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THE EFFECTS OF TARGET ORIENTATION ON THE DYNAMIC CONTRAST SENSITIVITY FUNCTION

by

Craig A. Croxton

Thesis submitted to the faculty of

Virginia Polytechnic Institute and State University

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in

Psychology

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THE EFFECTS OF TARGET ORIENTATION ON THE

DYNAMIC CONTRAST SENSITIVITY FUNCTION

by

Craig A. Croxton

Chairman: Albert M. Prestrude, Department of Psychology

(ABSTRACT)

Much research has been accomplished on the effects of target motion on visual acuity. Research has also been accomplished on the effects of target orientation on visual acuity. The contrast sensitivity function (CSF) also has been studied as a predictor of visual performance under dynamic conditions. However, no previous studies have combined these areas of research and examined the effect of target orientation on the Dynamic Contrast Sensitivity Function (DCSF).

This study examined the effects of target orientation on the DCSF and found that diagonal lines (relative to vertical lines) decreased the DCSF, on average over 19%. Previous research indicated that target motion reduces contrast sensitivity, and at the same time shifts the peak of the CSF toward lower spatial frequencies. This study rotated the target in a circular path (velocities of 22^{o}, 30^{o}, and 39^{o}/second) and found a similar decrement and shift in the CSF.

The main effects for Target Orientation, Velocity, and Spatial Frequency and their two-way interactions were all statistically significant ($p \leq .05$). Additionally, all velocity conditions were found to be statistically different from each other. These results advance the validity of our measurement device and procedures.

The effect of target orientation presumably is a function of the magnocellular and parvocellular visual pathway systems and their roles in the detection of form and motion. While the magnocellular system is primarily responsible for detection of motion and large objects, the parvocellular system is responsible for the detection of color and fine detail.

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Introduction

Static visual acuity (SVA)

Static visual acuity is the ability to resolve detail in a stationary stimulus (Scialfa, et al., 1988). Traditional tests of visual acuity (Snellen and Sloane letters, tumbling E's, Landolt C's, or the checkerboard pattern of the Bausch and Lomb Ortho-Rater) incorporate static, high contrast, and high spatial frequency targets with a static observer. These acuity tests are effective in determining the correction for the eye's refractive error. The smallest figure a person with standard visual acuity can resolve, at a viewing distance of 20 ft., is one that subtends one minute of arc on the retina (Riggs, 1965).

Dynamic visual acuity (DVA)

Dynamic visual acuity is the ability to discriminate detail in an object when relative movement exists between the observer and the object (Miller & Ludvigh, 1962; Reading, 1972a). Very few real world seeing tasks involve stationary observers or targets. For example, many of our every-day activities, such as walking, running, and jogging induce angular accelerations of the head. These dynamic conditions require oculomotor compensation to stabilize the observed image on the retina (Benson & Barnes, 1978).

Reading (1972a) found no statistically significant correlations between static and dynamic visual acuity. However, Burg (1966) found high intercorrelations between

static and dynamic visual acuity. The magnitude of these correlations decreased as target velocity increased (r = .673, .598, .541, .499, .350; for static, 60, 90, 120, and 150^{o}/sec., respectively).

Weissman and Freeburne (1965) also reported significant correlations between static and dynamic visual acuity up to target speeds of 120^{o}/sec. But, at the two fastest target velocities (150^{o}/sec. and 180^{o}/sec) the correlations were statistically nonsignificant.

Using factor analysis, Scialfa, et al. (1988) also found a significant correlation ($r = .52$) between static and dynamic visual sensitivity. They pointed out that only 25% of the variance in dynamic sensitivity can be accounted for by static sensitivity. Scialfa, et al. believe this figure is not larger because DVA is limited in part by visual pursuit accuracy while SVA is not. Brown (1972c) has provided evidence for this. Much of the variance remains unaccounted for because SVA does not predict pursuit accuracy. These data contributed to Prestrude's (1987) belief that traditional measures of visual acuity do not address visual acuity under dynamic conditions.

The general consensus among the DVA research is that target angular velocity is negatively correlated with the size of the target's smallest resolvable detail, or as target velocity increases, the minimum resolvable detail increases in size (Burg, 1966; Ludvigh & Miller, 1958; Miller, 1958;

Reading, 1972a; Weissman & Freeburne, 1965). Ludvigh & Miller (1958) determined the equation $Y = a+bx^3$ best described the shape of the DVA function for horizontal movement; where Y = visual acuity in minutes of arc, a = the predicted value of static visual acuity in minutes of arc, b = the dynamic acuity component, and x = target angular velocity in degrees per second (see Figure 1).

Insert Figure 1 about here

Miller & Ludvigh (1962) found that target angular velocities less than 40°/sec. had little effect on acuity, while velocities greater than or equal to 50°/sec. degraded acuity. Miller & Ludvigh (1962) and Morrison (1980) also reviewed studies using vertical and circular target movement; and those using observer movement relative to the target. They found DVA was most resistant to velocity effects with vertical movement and least resistant with circular movement. But, the general shape of the function between target angular velocity and the smallest resolvable detail remained similar for all three target motions. Additionally, there were no significant differences between observer movement (with a stationary target) versus target movement (with a stationary observer).

Miller (1958) also found subjects with superior DVA (velocity resistant subjects) maintained this superiority

(when compared to velocity susceptible subjects) regardless of the type of target motion. This supports the notion that DVA depends upon the entire oculomotor pursuit mechanism and not upon the strength of individual muscles.

Oculomotor pursuit mechanism

The deterioration of visual acuity during pursuit tracking results from erratic eye movements that cause unstable images on the retina (Miller & Ludvigh, 1962). The basic premise is that the oculomotor pursuit mechanism is only able to maintain a stable target image on the fovea up to a certain target velocity. At velocities greater than this, degradation in pursuit tracking occurs, stabilization of the image on the fovea degrades, and visual acuity decreases. This hypothesis is supported by studies measuring precise eye movements during pursuit tracking (Brown, 1972a, 1972c; Reading, 1972a, 1972b). Reading (1972b) found the eye's response latency is about 200ms with target velocities below 40^{o}/sec. This latency is followed by a high velocity saccade which fixates the retinal target image upon the fovea. A smooth pursuit movement follows this saccade and the image remains stabilized on the fovea. Resolution [image perception] takes place during this smooth pursuit phase (Crawford, 1960). If the initial saccade does not achieve fixation, then increases in subsequent saccades and pursuit velocities will occur (Brown, 1972c; Reading, 1972b). This process will repeat, attempting to reach fixation. This

effectively reduces the eye/target velocity mismatch, but fixation may still never be reached at the higher velocities.

The precise value of the target velocity where pursuit tracking breaks down is in contention. In their review of DVA research reports, Miller and Ludvigh (1962) and Morrison (1980), found no degradation of acuity with target velocities up to 40^{o}/sec; while target velocities of 50^{o}/sec. did degrade visual acuity. Reading (1972b) found no degradation of acuity with target velocities of 22^{o}/sec and 43^{o}/sec; while target velocities above 60-70^{o}/sec. degraded visual acuity.

Brown (1972c) found that target velocities greater than 25-30^{o}/sec. could not be smoothly tracked. Long and Homolka (1992) also found a decrement in DVA at target velocities as low as 30^{o}/sec. It is important to note that the reviews by Miller and Ludvigh (1962), and Morrison (1980), and Reading's study (1972b) allowed binocular pursuit while Brown (1972c) and Long & Homolka (1992) used monocular pursuit. This procedural difference may account for the differences in the critical velocities reported at which the pursuit mechanism was no longer able to stabilize the target image on the fovea.

Olesko (1992) found that target velocities as low as 25^{o}/sec. decreased contrast sensitivity. His subjects were required to binocularly track a target moving in an arcing (circular) path. Scialfa et al. (1988) points out that

rotary pursuit may be the most demanding and therefore difficult type of ocular pursuit. This procedural difference may explain why Olesko obtained differences in visual sensitivity at velocities as low as 25°/sec..

The human eye-brain system obtains the information necessary for pursuit tracking during the fixation and the pursuit states (Reading, 1972b). During the fixation state (the time prior to the first saccadic eye movement), information about the angular velocity of the object is evaluated. During the pursuit state (while the eye is tracking the object), differences between the angular velocities of the eye and target are evaluated. The saccadic system attempts to correct any remaining error between the target and fovea (Reading, 1972b). The output of the pursuit control system also may depend on feedback of acuity information. The finer the target's detail, the more accurate the acuity feedback information, and therefore, the more accurate the corrections for pursuit tracking (Reading, 1972b). This may explain why the eye velocities and target velocities matches found (100°/sec.) by Atkin (1969) far exceeded the matches found (30°/sec.) by Westheimer (1954). Atkin used a complex target while Westheimer used a non-complex target (a spot of white light).

While SVA is determined mainly by the resolving power of the eye, DVA demands much more of the oculomotor system (Hoffman, Rouse, & Ryan, 1981). Every-day tasks require the

oculomotor system to operate at a high degree of efficiency. Hoffman believes many every-day tasks require visual resolutions during velocities of 100°/sec. or more. For example, a 30 mph automobile produces a peak angular velocity of 84°/sec. when passing perpendicular to line of sight 30 ft. away (Hoffman et al., 1981).

<u>Why Study DVA</u>

Long and Penn (1987) support the increased use of DVA assessment testing in the areas of flying and driving. This support is based on two basic findings. First, numerous studies show that individuals with identical SVA often have very different DVA (Burg, 1966; Burg, 1971; Long & Penn; Ludvigh & Miller, 1958; Reading, 1972a). Second, Long and Penn cited studies demonstrating that DVA exceeds SVA as a predictor in tasks such as flying, driving, and athletics. For example, the DVA of pilots contributes more to their performance on various flying tasks (instrument reading, night flying, and formation flying) than does their SVA (DeKlerk, Eernst, & Hoogerheide, 1964). Prestrude (1987) also suggested that DVA should be a significant factor in the safe and efficient operation of aircraft. Burg (1971) compared driving records (accidents and convictions for traffic citations) with a battery of vision tests (DVA, SVA, lateral visual field, lateral phoria, low-illumination vision, glare recovery, and sighting dominance). In this battery, Burg found that DVA is the most closely related to

driving record. Falkowitz and Mendel (1977) found DVA to be positively correlated with the batting averages of Little Leaguers, while Sanderson and Whiting (1974) found DVA to be positively correlated with the ability to catch a ball.

Reading (1972a) pointed out that good SVA becomes a necessary, but not sufficient condition for good dynamic acuity. The studies presented above show that SVA tests may be inadequate as screening devices when used to assess tasks involving DVA.

Contrast Sensitivity

The ability of humans and animals to perceive the details of a scene is largely determined by the size and contrast of the scene (Campbell & Maffei, 1974; Campbell & Robson, 1968). Traditional vision measurements test the eye's ability to resolve fine detail with high contrast and high spatial frequencies (small) targets. However, contrast sensitivity measurements typically measure the ability to detect contrast across the full range of spatial frequencies (target sizes).

Sine wave gratings are used to examine visual sensitivity because they have the characteristics of contrast, frequency and phase (Committee on Vision, 1985). Additionally, through a process of Fourier transforms, any visual scene can be approximated by a combination of sine wave patterns (Campbell & Robson, 1968; Ginsburg, Evans, Sekuler, & Harp, 1982).

The term sine wave grating is descriptive because the transition from light to dark bars is regular, consistent, and follows a sine wave function. The contrast of the sine wave grating is defined as, $L_{max} - L_{min} / L_{max} + L_{min}$, where "L" is the luminance of the sine wave grating. This value may range from 0.0 to 1.0. Spatial frequency is the number of complete light/dark cycles that subtend one degree of visual angle; expressed as cycles per degree (cpd). The upper limit of human detection is at 60 cpd; while the lower limit becomes difficult to quantify because of practical limits of display size (Committee on Vision, 1985).

Contrast sensitivity, (the reciprocal of contrast threshold), is the minimum contrast at which one can distinguish a grating from a uniform field (Committee on Vision, 1985). The contrast sensitivity function (CSF) is constructed by measuring the contrast sensitivity for a range of spatial frequencies. According to Campbell and Maffei (1974), our peak sensitivity for the CSF is around the 3 cpd. However, recent studies using empirically measured contrast slides have placed the maximum sensitivity in the 5 - 8 cpd range (Adams, 1992; Olesko, 1992; Prestrude & Olesko, 1991).

Why Study the CSF?

The CSF provides us with information about one's visual ability that is absent in standard measures of visual acuity. Ginsburg, et al. (1982) found that the CSF was better than visual acuity for predicting a pilot's ability to detect

small, semi-isolated targets on the ground. They found a reliable correlation ($r = .83$; $p < .01$) between the peak region of photopic contrast sensitivity and slant range detection. Also, they did not find a reliable correlation ($r = -.13$) between photopic acuity and slant range detection. In this study, pilots in the simulator were required to land on a runway under differing visual condition. On random trials, an aircraft was presented on the runway and the pilot was required to press a button at the first detection of the MIG. The line of sight distance at button press was the recorded slant range.

In a field experiment conducted by Ginsburg, Easterly, and Evans (1983), pilots (seated perpendicular to the flight path of the incoming aircraft) were required to flip a response switch upon detection of an approaching aircraft. The distance at detection was recorded for analysis. A significant correlation between detection range and the CSF was found in eight of the ten trials. But, only three of the ten trials found significant correlations between detection range and Snellen visual acuity. By examining specific pilots' CSFs more closely, they were able to better illustrate the advantage of CSF over the Snellen test. Two pilots with equal Snellen acuity (20/15) had very different CSF at 4 and 8 cpd. The pilot with the superior CSF (by factors of 1.7 and 2.4 times) detected aircraft 1.57 miles further away. Also, the pilot with the best Snellen acuity

(20/10) did more poorly then a pilot with a superior CSF. In this case, the pilot with the superior CSF (by a factor of 1.9) still detected aircraft 945 ft sooner than the 20/10 pilot. These results led Ginsburg, et al.(1983) to conclude that contrast sensitivity is a better predictor of target detection distance than visual acuity.

In a different study, Hutton, Morris, Elias, Varma and Poston (1991) found many Parkinson's disease (PD) patients complained of poor vision even thought they had no ocular disease and normal visual acuity (as measured by standard testing). Upon further examinations, they found that CSF was reduced in Stage II or greater (Stages III - V) PD patients. They also found a correlation between CSF and PD severity: as PD severity progressed beyond Stage I, the CSF also decreased.

Hoehn and Yahr's (1967) five stages (I-V) of PD, were based on the patient's level of clinical disability. Stage I, II, and III PD patients are only minimally disabled, while stage IV and V patients are severely disabled. Stage I has unilateral involvement while Stage II has bilateral or midline involvement. During Stage III, the first signs of impaired righting reflexes manifests itself. With Stage IV PD, the patient an still walk and stand unassisted, but is markedly incapacitated. Stage V patients are confined to bed or wheelchair unless aided.

<u>Oblique effect</u>

The superiority in detecting vertically or horizontally oriented visual stimuli over diagonally (obliquely) oriented stimuli is the oblique effect (Appelle, 1972). This superiority in visual acuity is present in many different species (see Appelle, 1972) and may appear as early as 6 weeks in the human (Braddick, Wattam-Bell, & Atkinson, 1986; Leehey, Moskowitz-Cook, Brill, & Held, 1975). An interesting study by Annis and Frost (1973), raised the possibility that a developmental perspective might account for the oblique effect. They found the Cree Indians were not significantly effected by the grating orientations (horizontal, vertical, or oblique) while the Euro-Canadians were. They believe the acuity differences can be explained in that the orientation-specific detectors in humans are tuned by early visual experiences. Because the Cree are raised in a heterogeneous visual environment (a summer cook tent or winter lodge), they receive less exposure to vertical and horizontal stimuli than the Euro-Canadian subjects (raised in a carpentered environment). This difference in exposure to contour orientations in the early visual environment may account for differences in visual acuity in later life.

One method used to determine the presence of the oblique effect involves measuring the visual evoked potentials (VEP). The VEP is a summed cortical response resulting from a temporal change in some characteristic (e.g. intensity) of the visual stimulus impinging on the eye (Dobson & Teller,

1978). This basic experimental paradigm compares the VEP of a horizontal or vertical grating to that of an oblique grating. If the VEP of the horizontal or vertical grating is greater than that of the oblique grating, then the assumption is that the subject has better visual sensitivity to the vertical (or horizontal) grating. Sokol, Moskowitz, and Hansen (1987) examined visual evoked potentials (VEP) in infants to determine the presence of the oblique effect. Not only did they find lower VEP amplitudes for oblique targets (45°), but they also found longer VEP latencies. These results would imply that the Cree Indians' (Annis & Frost, 1973) VEP's for vertical targets would be equal in amplitude and latency to their VEP's with oblique targets.

Studying the dynamic contrast sensitivity function (DCSF)

I have attempted to highlight the need for a supplemental test to traditional visual acuity testing. We've seen how SVA measures are poor predictors of DVA and the CSF. Also, studies show that both DVA and the CSF are superior predictors to SVA in some visually guided tasks. The next logical step would be to investigate the CSF under dynamic conditions (DCSF). The Committee on Vision of the National Academy of Sciences (1985) recommended the relationship between DCSF and flying be compared with the relationship of CSF and flying.

The purpose of this research was to examine and establish a data base of the DCSF. To date, very few studies

(see Olesko, 1992; Scialfa, et al., 1988) have incorporated angular velocity with the CSF. Like Olesko's (1992) study, I examined a wider range of spatial frequencies than Scialfa, et al. (1988). The major difference of this experiment from Olesko's experiment was the inclusion of an oblique orientation. Even in our "carpentered visual environment" (Annis & Frost, 1973), much of what we see has oblique orientations. Because the final goal is to develop a test that can be used to predict performance during certain complex visual tasks, the inclusion of oblique gratings provides additional data more closely resembling real world visual scenes. Additionally, the oblique gratings allowed us to examine if the same oculomotor mechanisms operating with vertical and horizontal gratings, are present with oblique gratings. Because the oblique effect is most pronounced at the 45° orientations (Campbell, Kulikowski, & Levinson, 1966), this testing may provide us with the most sensitive measure of the DCSF.

This study examined the effects of three major factors: spatial frequency; angular velocity; and target orientation; on the DCSF. This study examined spatial frequencies (1.0, 2.0, 3.0, 5.0, 7.0, 10.0, 15.0, and 20.0 cpd) covering much of the human visual system's capabilities of target detection. We expect to see the inverted-U shape function with peak sensitivity in the 3-7 cpd range for the static conditions.

The angular velocities of 0°, 22°, 30°, and 39°/sec. were used. The apparatus generating these velocities presented rotary movement. Although, most movement we normally detect is rarely circular, rotary movement is the easiest to instrument in a small apparatus, and it taxes the oculomotor system more than other forms of movement (Prestrude & Olesko, 1991; Scialfa, et al.. 1988). As the target's velocity increased, we expected to see a resultant decrease in contrast sensitivity indicated by a lowered peak and a shift of the peak sensitivity toward lower spatial frequencies, and an increase in the contrast required to detect the lower spatial frequencies (a decrease in the overall contrast sensitivity). This prediction is in line with the results of earlier DVA studies (Adams, 1992; Olesko, 1992; Scialfa, et al., 1988).

Finally, the target orientations were vertical or oblique ($+45^{\circ}$ from vertical). The horizontal orientation was not included because numerous studies have shown no statistically significant differences between the horizontal and vertical orientations (Annis & Frost, 1973; Campbell, et al., 1966; Leehey, et al., 1975). In the static conditions, the CSF should be less in the oblique orientation than in the vertical orientation. Also, the shifting of the peak of the CSF toward the lower spatial frequencies for oblique orientations should occur at slower velocities than the

shifting of the CSF for vertical orientation. This prediction is based on the longer VEP Sokol, et al. (1987) found for oblique orientations. Increasing the target's velocity, in essence, places a greater penalty on any time delays in the oculomotor pursuit mechanism. This is because the distance traveled by the target per unit of time is changed by a factor directly related to the ratio of the velocity change (a factor of two when increasing from 25 to 50^{o}/sec.; a factor of four when increasing from 25 to 100^{o}/sec.). Therefore, any time delays under dynamic conditions should increase the demand on the oculomotor system, exacerbate the tracking difficulties, and result in the CSF shifting sooner (at lower velocities) than in the vertical CSF.

Pilot studies

Three pilot studies were completed to evaluate our methodology. The first pilot study identified two perceptual phenomena that required changes in the procedures.

Procedurally, subjects viewed the test targets one spatial frequency at a time, but with the contrast ratios in random order. For each target presented subjects responded with a "yes" (detect a contrast grating) or "no" (did not detect a contrast grating). Included in each spatial frequency set, was a randomly placed uniform gray (0.0 contrast) target. Many subjects were reporting greater than 50% "yes" on the uniform gray slides. What subjects were

perceiving on the uniform gray slide was an after image from the previous high contrast slide. This led us to change our procedures to a staircasing method of limits. Also, I increased the inter stimuli interval for 3 to 5 seconds to 7 to 10 seconds to further reduce the effects of afterimaging.

The second interesting phenomenon I observed was similar to perceptual aliasing. [Perceptual] aliasing is a false neural representation of a stimulus beyond the resolution limit (Thibos, Walsh, & Cheney, 1987). During [perceptual] aliasing, retinal image components above the resolution limit will be signaled by the neural array, but be represented falsely and appear as components below the resolution limit (Thibos, et al., 1987). Some subjects reported seeing "two to three" lines in the Medium and Fast velocity conditions with the higher spatial frequency slides (15 and 20 cpd). These slides actually had approximately 20 and 26 visible lines. Because the original procedures did not ask the subjects how many lines they saw, many of the subjects were answering "yes" (when they perceived only two or three lines) when they should have been answering "no". To prevent a "yes" answer when this occurred, the instructions were changed to ask the subjects to respond "no" when the image they saw differed from the reference slide (Appendix B).

In the second pilot study, I had mechanical difficulties. The rotating mechanism would bind causing inconsistent velocities. To alleviate this problem, I

replaced the original rotating mechanism (a Lazy Suzy) with a machined aluminum carriage with ball bearings.

In a third pilot study, the modifications in apparatus and procedure from the preceding test pilot studies were tried on four subjects. The initial repeated measures analysis of variance (ANOVA) showed main effects for target Orientation ($F(1, 3) = 12.44$, $p = .0387$), Velocity ($F(3, 9) = 14.65$, $p = .0008$), and Spatial Frequency ($F(7, 21) = 12.27$, $p = .0001$) (see Figure 2). No interactions were found to be statistically significant .

Insert Figure 2 about here

A contrast analysis between the four velocity conditions found significance between the following conditions: Static vs Medium [$F(1, 3) = 15.89$, $p = .0283$]; Static vs Fast [$F(1, 3) = 32.77$, $p = .0106$]; Slow vs Medium [$F(1, 3) = 29.67$, $p = .0122$]; and Slow vs Fast [$F(1, 3) = 12.29$, $p = .0393$] (see Figures 3 and 4). All other velocity contrasts were nonsignificant at the $p = .05$ level. However, the Static vs Slow condition did approach significance with a of $p = .0911$.

Insert Figures 3 and 4 about here

The pilot data suggested the following hypotheses: 1) effect of orientation - the contribution of this thesis; 2)

effect of velocity - replicates previous results; and 3) effect of spatial frequency - replicates previous results.

Method

Subjects

A total of 39 undergraduate psychology students from Virginia Polyetchnic Institute and State University signed up to participate. They all received extra credit for participation. Seven subjects were not included in the data base for the following reasons: a) SVA was greater than 20/25 (N = 1); b) did not complete both testing sessions (N = 3); and c) exceeded 25% false alarm rates on the catch trials ([N = 3], see procedures). All subjects had at least 20/25 near and far static binocular visual acuity (measured by the Bausch & Lomb Orthorater, model 6000). This experiment was approved by the VPI & SU Human Subjects Review Board.

Apparatus

Each subject was screened for near and far static binocular visual acuity with a Bausch & Lomb Orthorater, model 6000 (plates N-1 and F-3).

The portable dynamic contrast sensitivity device (PDCSD) developed by Olesko (1992), and modified by the present author, measured the CSF, as well as the DCSF (see Figure 5).

Insert Figure 5 about here

The PDCSD, included a modified Kodak 850H slide projector. A thin, flat black aluminum sheet, with a 0.635 cm diameter hole was placed in front of the projector bulb so the bulb illuminated only the center of the target slide. This produced a circular test target while also reducing the size of the projected image. The path of the projected image was through a right angle prism, onto a front surface mirror positioned at a 45° angle to a ground glass screen on which the image was back projected.

The prism was mounted inside a circular frame and was rotated by a drive belt connected to a variable speed electric motor. A Marietta Kinetic Visual Display variable resistance potentiometer controlled the motor and regulated the target velocities. Because the front surface mirror was also attached to the rotating circular frame, it remained in the same relative position with respect to the refracting prism. The 7.2 cm displacement of the mirror from the prism's reflecting surface formed the radius of the circular path traveled by the test targets. A 40 x 33 x 61 cm wooden box housed the rotating prism/mirror assembly and motor. A hole was cut into the rear of the box allowing for the slide projector's lens. A ground glass screen was located in the box and an adjustable circular aperture was mounted in front of the screen to control exposure duration. A neutral density filter (log 2.0) was affixed to the front of the projector's lens to reduce glare. A Lafayette timer coupled

with a Gerbrand shutter set the duration of the exposure at 400 ms. in the static condition. The adjustable aperture kept the exposure duration at 400 ms. in the moving target conditions. A black muslin cloth tunnel lined the visual path from the subject's eyes to the target image. This reduced any ambient light.

The test targets were a series of slides with sine wave grating produced by a VAX 11-785 computer on a Perceptics 9200 color image processor. The slides were photographed by a Matrix Instruments Model 4007 Color Graphic Camera using 100 ASA Kodak T-Max black and white film. The negatives were mounted into slide frames to create the slides. The test set (Appendix A) consisted of 92 slides at eight spatial frequencies (1, 2, 3, 5, 7, 10, 15, and 20 cpd). The projected circular test targets subtended 1.32 degrees of visual angle at a viewing distance of 82.6845 cm.

The contrast ratios of the test targets were empirically determined using a Gamma Scientific Radiometer which scanned the center 1.0 cm of the target slides (Appendix A). An exception to this was with the 1.0 cpd slides which required a 2.0 cm scan to ensure the inclusion of at least one peak and trough in the data. An aperture of 25 x 8 mm and a step size of .003 cm was used to obtain the individual data points. The average of the peaks (L_{max} avg.) and the average of the troughs (L_{min} avg.) were used in our contrast ratio equation ($[L_{max}\text{ avg.} - L_{min}\text{ avg.}]/[L_{max}\text{ avg.} + L_{min}\text{ avg.}]$). The

unit of luminance used in calculating the contrast ratios was candelas per meter squared (cd/m^2).

The targets were presented either vertically or obliquely (45^o clockwise). The projector was placed on a incline in order to achieve the 45^o clockwise orientation.

The optical power of the test targets was measured directly from the screen with a Minolta Luminance Meter 1^o and a No. 135 close up lens. The average luminance of the test targets was 7.93 cd/m^2 (SD = 1.26 cd/m^2).

Procedure

For each subject, two testing sessions completed the data collection. Subjects were assigned randomly to two groups, a "V" and a "O" group. The "V" group received the vertical targets during the first session, and the oblique targets during the second session. The "O" group received the oblique targets during the first session, and the vertical targets during the second session.

The possible effects of practice and fatigue were minimized by using a row complete Latin squares design for both the velocity ordering and the spatial frequency ordering. A row complete Latin squares design is "statistically 'balanced' both with respect to the effect of the immediately preceding experiment and also with respect to the number of preceding experiments" (Dénes & Koedwell, 1974, p. 82). In repeated measures experiments, a row complete Latin squares may be advantageous if the subject is likely to

be affected by the number of treatments previously received, and also by the effect of the treatment which was its immediate predecessor (Dénes & Koedwell).

The "V" group was divided further into four velocity groups (W, X, Y, Z); with each group containing all velocity conditions. Each subject began with one velocity, but responded to all four velocities. Each velocity group had four subjects, and each subject received one of the eight spatial frequency orderings, "A" through "H" (see Figure 6). Likewise, the same division of subjects was used for the "O" group. Therefore, each subject responded to all combinations of orientation, velocity, and spatial frequency.

Insert Figure 6 about here

During the start of the first session, each subject was tested for near and far static binocular visual acuity (Orthorater). Those who normally wore corrective lenses did so during the testing.

The subjects viewed the test targets one spatial frequency at a time with decreasing levels of contrast. Each trial set started with a static presentation (1-2 seconds duration) of a reference slide. The reference slides were the highest contrast slides for each spatial frequency set. They ranged in contrast from a high of .5655 (for the 1 cpd set) to a low of .4229 (for the 5 cpd set). A uniform gray

slide (0.0 contrast) was included in each spatial frequency set. Its position in each set was subsequent to the slide with greater than 10% contrast and prior to the first slide with less than 10% contrast (see Appendix A). This created a somewhat random placement of the sequential position of the uniform gray slides due to the differing numbers of slides subsequent to, and prior to the 10% contrast level. If the subject responded "yes" to more than 25% of the catch trials, the data set was not used and the subject was dismissed and thanked for his/her participation (three subjects exceeded 25%).

To determine contrast thresholds, a staircasing method of limits was used. For each target presented, subjects were instructed to respond with "yes" (detect a contrast grating the same as the reference slide) or "no" (did not detect a contrast grating the same as the reference slide). Once a "no" was obtained the same slide was presented again. If the response was another "no", the slides were reversed (contrast increased) until a second "yes" was obtained. If the response after the first "no" was "yes", then the contrast was decreased until a second "no" occurred. The individual's contrast threshold was the average contrast between the two "yes/no" slides (The catch slides were not used in calculating thresholds). The two exceptions to this averaging procedure occurred when a subject could not detect the highest contrast target (first slide presented after the

reference slide), or when the subject was able to detect the lowest contrast slide (last slide). In these situations, the contrast threshold used for averaging was that of the first and last slide respectively. Statistically, this is a conservative approach. In the first condition, we know the individual's "true" threshold is somewhere between 1.0 and the contrast value of the slide. By using the contrast value of the first slide, we are reducing any differences that might be found between our testing conditions. In a similar manner, by using the value of the last slide, we are also reducing any differences that might be found between our testing conditions.

The interstimulus interval was approximately seven to ten seconds during the testing conditions. This slower presentation allowed any afterimages that may have been present to dissipate, while keeping the duration of the testing to less than 60 minutes, thus minimizing subject fatigue.

During all testing conditions, the target exposure was held at 400 ms. This 400 ms exposure time allows the eye at least an initial saccade, and at least one smooth pursuit movement (Miller & Ludvigh, 1962). The targets were exposed to 100, 140, and 180 degrees of arc during the 22, 30, and 39^{o}/sec. conditions respectively. The targets covered a linear extent of 12.5, 17.5, and 22.5 cm. respectively.

After the static visual acuity test, subjects were seated in front of the PDCSD with the head stabilized in a chin rest. The projected image was level with the subject's eyes. An adjustable height seat was used to minimize muscle fatigue. A red incandescent bulb (25 watts) provided the only illumination other than test images. This lighting allowed the experimenter to record the data without interfering with the subjects' adaptation (Olesko, 1992).

Approximately ten minute of adaptation occurred prior to the actual testing. During this time, subjects were instructed (refer to Appendix B) that they were participating in an experiment on the effects of spatial frequency, target orientation, and target movement on their ability to detect sine wave grating patterns.

For demonstration purposes prior to data collection, subjects were shown a set of practice test targets of vertical or oblique orientations (depending on the testing condition). A set of eleven slides, with frequencies ranging from 1.5 to 25 cpd were used during the demonstration. During the demonstration, subjects received sample threshold determinations in all velocity conditions (0°, 22°, 30°, and 39°/sec) with the 1.5 cpd slides. These demonstrations gave the subjects ample practice and familiarized them with the required procedures.

Results

All threshold measurements were converted to contrast sensitivity values (threshold^{-1}) prior to the analyses. Traditionally, the contrast sensitivity values and not the threshold values are plotted. By converting to contrast sensitivity, one can make direct statistical and visual comparisons when viewing contrast sensitivity function plots.

A 2 x 2 x 4 x 4 x 8 x 8 (Orientation Ordering x Orientation x Velocity Ordering x Velocity x Spatial Frequency Ordering x Spatial Frequency) ANOVA is summarized in Table 1.

Insert Table 1 about here

Factors: Orientation, Velocity, and Spatial Frequency

The ANOVA revealed main effects for target Orientation ($F(1, 30) = 18.09$, $p = .0002$), Velocity ($F(3, 180) = 160.29$, $p = .0001$), and Spatial Frequency ($F(7, 1680) = 196.18$, $p = .0001$).

Additionally, all of the two-way interactions between Orientation, Velocity, and Spatial Frequency were significant (Orientation x Velocity, $F(3, 180) = 3.96$, $p = .0092$; Orientation x Spatial Frequency, $F(7, 1680) = 3.24$, $p = .0012$; and Velocity x Spatial Frequency $F(21, 1680) = 29.35$, $p = .0001$.

The Fisher's LSD contrast analyses between the velocity conditions yielded significance between each adjacent velocity condition (see Table 2).

Insert Table 2 about here

The three-way interaction between Orientation, Velocity, and Spatial Frequency Ordering was not significant ($F(21, 1680) = 0.61$, $p = .9708$).

Factors: Orientation Ordering, Velocity Ordering, Spatial Frequency Ordering

No main effects were found for Orientation Ordering ($F(1, 30) = 2.09$, $p = .1588$), Velocity Ordering ($F(3, 180) = 1.14$, $p = .3326$), or Spatial Frequency Ordering ($F(7, 1680) = 1.17$, $p = .3194$).

Interactions between the six factors

The Orientation x Spatial Frequency Ordering interaction was statistically significant ($F(7,1680) = 2.59$, $p = .0116$). The remaining interactions between the six factors were not significant ($p \geq .05$).

Duncan's Multiple Range Test

A separate Duncan's Multiple Range Test was performed to determine which velocity conditions differed at each spatial frequency in both the Vertical and Oblique orientation. These results are summarized in Tables 3-18.

Insert Tables 3-18 about here

The results clearly indicate that the oblique orientation decreases the CSF when compared to the vertical orientation (see Figure 7).

Insert Figure 7 about here

The overall percentage decrement in the CSF at given spatial frequencies is shown in Figure 8. On average, the CSF decreased 19.35% (standard error = 2.72%) from the vertical to the oblique orientation.

Insert Figure 8 about here

A line of best fit was constructed (see Figure 9) for the Average % Decrements in the CSF. The slope of this line was not statistically different from zero ($p = .06$).

Insert Figure 9 about here

The results also indicated a decrement in the CSF when rotational movement as low as 22°/second was applied to the targets. The CSF also continued to decrease (from

22^{o}/second) at target velocities of 30^{o}/second and 39^{o}/second (see Figures 10, 11, and 12).

Insert Figures 10, 11, and 12 about here

In the Vertical condition, the peak sensitivity shifted from 5 cpd (static condition) to 3 cpd in the slow and medium velocity conditions and remained the same in the fast condition (see Figure 10).

Figures 13 and 14 graphically represent the percentage decrement in the CSF when comparing the Static condition to the Slow, Medium, or Fast velocity condition.

Insert Figures 13 and 14 about here

In the Oblique condition, the peak contrast sensitivity shifted from 5 cpd (static condition) to 3 cpd in the slow velocity condition, and from 5 cpd to 2 cpd in fast velocity condition (see Figure 11). Peak sensitivity remained the same in the medium velocity condition.

Discussion

The results of this study clearly show a significant ($p = 0.0002$) decrement in the CSF due to the oblique effect. This decrement is not surprising given the robustness of the oblique effect. However, what is surprising was the

magnitude of the oblique effect. Contrast sensitivity was reduced, on average, 19.35% (see Figures 8 and 9).

The analysis of the slope of the regression line showed it was not statistically different from zero ($p > .05$). This leads me to the conclusion that the average decrement due to the oblique effect is independent of spatial frequency.

The demonstration of the oblique effect with our procedures, advances the validity of our measuring device and procedures. Appelle (1972) pointed out that the literature demonstrated the oblique effect in many species including (i.e., octopus, goldfish, pigeon, rat, squirrel, cat, chimpanzee, and human). Braddick et al. (1986) and Leehey et al. (1975) also found the oblique effects may occur as early as 6 weeks in the human infant. Orientation-specific masking and orientation-specific color aftereffects studies also demonstrate the oblique effect (see Appelle, 1972 for a review). Because of this robustness, had we not found an oblique effect, then we would have to question our methods and procedures. But given that we did find the oblique effect, and our data are also in agreement with other DCSF studies (Adams, 1992; Olesko, 1992; Scialfa, et al., 1988), the utility, generality, and validity of the PDCSD is strengthened.

The amount of change (when compared to the static condition) that was exerted by moving targets was greater for the vertical than oblique targets ($p = .0092$).

Insert Figures 15 - 17 about here

Figures 15-17 graphically represent this Orientation x Velocity interaction. A possible explanation for this interaction is the floor effect. The CSF for the Vertical targets in the Static condition is much greater than the CSF for the Oblique targets (i.e., the oblique effect). Therefore, the amount of decrement available under the differing velocity conditions is much larger for the vertical targets than for the oblique targets.

The Orientation x Spatial Frequency interaction also reached significance ($p = 0.0012$). This interaction is not readily apparent in Figure 12 due to the log-log scaling. For example, the change from 2 to 3 cpd in the Vertical orientation, Static condition, appears equal in magnitude to the change (2-3 cpd) in the Oblique orientation, Static condition. However, the contrast sensitivity increased by approximately 47% (from 2-3 cpd) in the Vertical condition and only 38% (from 2-3 cpd) in the Oblique condition.

A possible explanation for this interaction lies in the construction of our visual system. Our visual system is mediated by three parallel pathways (the magnocellular, parvocellular interblob, and the parvocellular blob) that process information for motion, depth and form, and color (Kandel, 1991).

The magnocellular system is specialized for motion and spatial relationships (Kandel, 1991). It also includes the large "M" ganglion cells found in the retina which are most sensitive to large images (low spatial frequencies).

The parvocellular-interblob system is primarily specialized for the detection of form (Kandel, 1991). It includes the small "P" ganglion cells in the retina that are sensitive to different colors. The neurons in this system are also sensitive to orientation of edges. They are also slowly adapting and capable of high resolution [high spatial frequencies] (Kandel).

The parvocellular-blob system is primarily specialized for the detection of color (Kandel, 1991). It also receives information from the "P" ganglion cells in the retina.

Appelle (1972) points out that we have separate sets of analyzers for different orientations. This idea is in agreement with Hubel and Wiesel's (1962) observations of simple and complex cells that are tuned specifically to a particular orientation. The complex cells are arranged into columns in the primary visual cortex and each column is maximally responsive to a specific orientation (Kandel, 1991). A lateral grouping of these columns, each responsive to a different orientation (approximately a 10 degree shift in axis of orientation) forms what Hubel and Wiesel called hypercolumns.

The distribution of these hypercolumns combined within the magnocellular and/or parvocellular systems might explain the Orientation x Spatial frequency interaction.

The Velocity x Spatial Frequency interaction may also be explained by the construction of our visual system. Inspection of Figures 10 - 12 show that contrast sensitivity decreased as velocity increased. Also, the degradation was greater at the higher spatial frequencies than the lower spatial frequencies. Miller and Ludvigh (1962) pointed out that the deterioration of visual acuity during pursuit tracking results from erratic eye movements that cause unstable images on the retina.

Retinal "smear", a blurring of the contrast between adjacent areas of the retina (Adams, 1992) may be responsible for this interaction. When viewing high spatial frequency images, the magnitude of the image's movement on the retina needed to cause smearing would be less than that for lower spatial frequency images. Therefore, retinal smear would manifest itself at a slower velocity with high spatial frequency targets than with low spatial frequency targets. Also, at a given velocity, the retinal smear would be greater for the higher frequency targets. This explains why velocity exacts a larger toll at the higher spatial frequencies.

Another result of this study was that the peak of the CSF appears to shift toward lower spatial frequencies with velocity. Examination of Figure 10 shows the peak contrast

sensitivity in the Static condition at 5 cpd. But, under the Slow and Medium velocity conditions, the peak contrast sensitivity is at 3 cpd. In the Fast condition, the CSF is depressed and no peak is apparent (the value at 5 cpd is the greatest but the value a 2 cpd is also very close in magnitude). Figure 11 shows the peak sensitivity shifting from: 5 to 3 cpd (Static to Slow); and 5 to 2 cpd (Static to Fast). The Medium velocity condition maintained the same peak as the Static condition.

The reason for the shift in peak sensitivity can be logically explained by the functional anatomy of our visual system. The magnocellular system is most sensitive to both movement and large targets (i.e.., low spatial frequencies). Therefore, any target movement should increase the relative contribution of this system over that of the parvocellular systems. This increased relative contribution would explain the shifting of peak sensitivity toward the lower spatial frequencies.

The prediction that the peak of the CSF would shift toward lower spatial frequencies at slower velocities for the oblique orientation (when compared to the vertical orientation) was not supported by the data (see Figure 12). We found a similar shift (both from 5 to 3 cpd) in both peaks at the slowest velocity employed (22°/second). This finding does not eliminate the possibility that our prediction would hold true at slower velocities. For our prediction to still

be valid, one must assume that our slow velocity was too fast, and placed too great a demand on the Vertical condition, thus it was unable to differentiate the proposed difference between the Vertical and Oblique conditions.

The results of this study, like Olesko's (1992) found significant decrements in the CSF at much slower velocities (22^{o}/sec. and 25^{o}/sec.) than previous DVA research (Miller & Ludvigh, 1962, $\geq 50^{o}$/sec.; Weissman & Freeburne, 1965, $\geq 150^{o}$/sec.). This finding may be attributed to three methodological differences in the research: 1) target contrast levels; 2) target movement; 3) subject head movement. Typical DVA studies used Landolt rings which may have had higher contrast levels than our sine wave gratings (I can only speculate on this because the contrast levels in the earlier studies were not reported. However, typically, the background was white with black targets). This higher contrast may have allowed the subjects to more accurately track the targets at higher velocities. This explanation concurs with Brown's (1972b) findings that their highest contrast level (70%) resulted in the lowest acuity thresholds at all velocities. Circular movement was reported to be more taxing on the ocular pursuit mechanism than the vertical or horizontal movements typically used (Miller & Ludvigh, 1962; Morrison, 1980). The present study moved the target in a circular motion perpendicular to the line of sight while traditional studies used vertical or horizontal movement.

Therefore, we would also expect a significant difference at slower velocities when compared to traditional studies employing vertical or horizontal movement. Crawford (1960) found that free head movement improved DVA when compared to a fixed head. This study required a fixed head position (see Appendix B) while Weissman and Freeburne (1965) allowed free head movement in tracking. This third factor would also lead to a significant difference for slower velocities.

The row Latin square design was intended to minimize practice and fatigue effects. However, this design and our analysis allowed us to examine possible ordering effects for orientation, velocity, and spatial frequency. The only ordering effect that reached significance ($p = .0116$) was the interaction between the Orientation and the Spatial Frequency Ordering. The large number of tests accomplished (given the six factors) increased the probability of making a Type I Error, and this may be the only logical explanation for this statistically significant interaction.

The results of this study served to validate the utility of the PDCSD as a tool for measuring dynamic contrast sensitivity. Future research should test additional orientations (e.g., 15^{o}, 30^{o}, 60^{o}, 75^{o}, and horizontal). This would allow a testing of the precision of the test measurement and might also suggest what mechanisms are involved in the orientation effect and its interaction with velocity and spatial frequency.

The subsequent step in this area of research needs to examine the validity of the DCSF in predicting real-world performance in such areas as flying, driving, and athletics.

Even if future research can establish predictive validity of the DCSF in real-world performance, the testing methods must become more efficient to be effectively used. Increased testing efficiency should be the follow on step (i.e.., after predictive validity is established) for future research.

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Appendix A

Test Slides and their Empirically Measured Contrast Levels

Photo	**Contrast**	CPD	Amplitude	Period	Phase	Offset	**Avg contrast**
113	.5655	1	50	250	1.45	100	
114	.3146	1	20	250	1.45	100	.44005
115	.2840	1	15	250	1.45	100	.29930
116	.2207	1	10	250	1.45	100	.25235
117	.2061	1	9	250	1.45	100	.21340
118	.1487	1	8	250	1.45	100	.17740
121	.1218	1	5	250	1.45	100	.13525
UG							
122	.0838	1	4	250	1.45	100	.10280
123	.0809	1	3	250	1.45	100	.08235
124	.0680	1	1	250	1.45	100	.07445
201	.4646	2	50	125	1.45	100	
202	.1074	2	10	125	1.45	100	.28600
UG							
203	.0844	2	7	125	1.45	100	.09590
204	.0812	2	6	125	1.45	100	.08280
205	.0547	2	5	125	1.45	100	.06795
206	.0436	2	4	125	1.45	100	.04915
207	.0388	2	3	125	1.45	100	.04120
208	.0329	2	2	125	1.45	100	.03585
210	.0264	2	0.9	125	1.45	100	.02965
211	.0203	2	0.8	125	1.45	100	.02335
302	.4521	3	50	85	1.45	100	
303	.1205	3	10	85	1.45	100	.28630
UG							
304	.0860	3	7	85	1.45	100	.10325
305	.0764	3	6	85	1.45	100	.08120
306	.0618	3	5	85	1.45	100	.06910
307	.0542	3	4	85	1.45	100	.05800
308	.0351	3	3	85	1.45	100	.04465
310	.0245	3	1	85	1.45	100	.02980
311	.0205	3	0.9	85	1.45	100	.02250
312	.0192	3	0.8	85	1.45	100	.01985
401	.4229	5	50	50	1.45	100	
UG							
402	.0739	5	7	50	1.45	100	.24840
403	.0598	5	6	50	1.45	100	.06685
405	.0369	5	4	50	1.45	100	.04835
406	.0296	5	3	50	1.45	100	.03325
408	.0182	5	1.5	50	1.45	100	.02390
409	.0171	5	1	50	1.45	100	.01765

410	.0168	5	0.9	50	1.45	100	.01695
411	.0133	5	0.8	50	1.45	100	.01505
501	.4516	7	50	37	1.45	100	
502	.2050	7	20	37	1.45	100	.32830
503	.1555	7	15	37	1.45	100	.18025
504	.1083	7	10	37	1.45	100	.13190
UG							
505	.0841	7	8	37	1.45	100	.09620
506	.0767	7	7	37	1.45	100	.08040
507	.0693	7	6	37	1.45	100	.07300
508	.0572	7	5	37	1.45	100	.06325
509	.0495	7	4	37	1.45	100	.05335
510	.0365	7	3	37	1.45	100	.04300
511	.0296	7	2	37	1.45	100	.03305
512	.0212	7	1	37	1.45	100	.02540
601	.4423	10	50	25.5	1.45	100	
602	.1967	10	25	25.5	1.45	100	.31950
603	.1537	10	20	25.5	1.45	100	.17520
604	.1049	10	15	25.5	1.45	100	.12930
UG							
605	.0858	10	10	25.5	1.45	100	.09535
606	.0568	10	8	25.5	1.45	100	.07130
608	.0471	10	5	25.5	1.45	100	.05195
609	.0382	10	4	25.5	1.45	100	.04265
610	.0290	10	3	25.5	1.45	100	.03360
611	.0190	10	2	25.5	1.45	100	.02400
701	.5075	15	75	17	1.45	100	
702	.3849	15	50	17	1.45	100	.44620
703	.3204	15	40	17	1.45	100	.35265
704	.2455	15	30	17	1.45	100	.28295
705	.1681	15	20	17	1.45	100	.20680
706	.1293	15	15	17	1.45	100	.14870
UG							
707	.0873	15	10	17	1.45	100	.10830
708	.0740	15	8	17	1.45	100	.08065
709	.0544	15	6	17	1.45	100	.06420
710	.0377	15	4	17	1.45	100	.04605
711	.0206	15	2	17	1.45	100	.02915
712	.0153	15	1	17	1.45	100	.01795
714	.4466	20	65	12.8	1.45	100	
715	.4197	20	60	12.8	1.45	100	.43315
716	.3985	20	55	12.8	1.45	100	.40910
717	.3654	20	50	12.8	1.45	100	.38195
718	.3333	20	45	12.8	1.45	100	.34935
719	.3065	20	40	12.8	1.45	100	.31990
720	.2698	20	35	12.8	1.45	100	.28815

721	.2358	20	30	12.8	1.45	100	.25280
722	.1613	20	20	12.8	1.45	100	.19855
UG							
723	.0826	20	10	12.8	1.45	100	.12195
724	.0434	20	5	12.8	1.45	100	.06300

Appendix B

Instructions for Subjects

First, I'll test your far and near visual acuity. Please have a seat at the table. Adjust your chair so your chin rests comfortably in the chin rest. Please keep your chin in the chin rest unless instructed otherwise. Go ahead and relax right now. There will be several breaks to relax and remove your chin.

Your task will be to look at the circle of light in front of you and determine whether you can see a pattern of vertical (*diagonal*) bars. This circle will be visible for less than a second. Some images may be very faint or non-existent; while others will be easily seen. Answer "yes" or "no" to whether you see the bars. If you are not sure, make a best guess. Prior to beginning each set, I'll show you a reference slide for that set. For each set, the amount of bars and their direction of slant will remain the same as the reference slide. Continue to answer yes, until you no longer see any bars **or** the number of bars you see differs from the reference. For example, if you initially see 10 bars, and then only see 3-4 bars on future images of the same set, then you would report "no" when you started to see only 3-4 bars. You will probably not be able to count all the bars, so make your best guess (1 or 2; 5 to 10, 15; too many to count; are some examples). It's not important that you count the exact

number of bars, but it is important that you use your initial estimation of the reference slide for the remainder of the slides in the set.

LIGHTS OUT!!!!!!!!

I'll will demonstrate some of the images you may see. Place your chin in the chin rest.

***SLIDE 1, 314*:** This image has 5 bars. Do you see them?

***SLIDE 2*, 513:** This image has about 10 bars. Do you see them?

***SLIDE 3, 515*:** This image has the same amount of bars, but is a bit more difficult to see than the last. Do you see them?

***SLIDE 4, 801*:** This image has LOTS of bars. Do you see them?

Some of the images will have either more or less bars, and will be harder or easier to see.

***SLIDE 5, 125*:** For example, this image only has two bars. Do you see them?

We will begin each trial with a "Let me know when you are ready." With a "Ready", we will begin the trial. Remember to place your chin in the chin rest prior to answering.

Now we will do a quick practice trial demonstrating the short duration of the image. "Let me know when you are ready." *(Proceed in the static condition with the 6 trial*

slides @ .4 sec. duration. I've selected the slides to be, 213, 214, UG, 215, 218, 224.)

In another phase of testing, we will be moving the images. Once again, answer "yes" or "no". During each trial set, the moving target will appear at same initial point. I will tell you where the target will appear prior to starting each velocity trial. You should attempt to follow the target with your eyes when it appears to when it disappears. For example, this target will appear near the 10:00 position and disappear near the 2:00 position. *(Set the speed to SLOW, adjust the aperture to 100°, and demonstrate with slides 213, 214, UG, 215, 218, 224.) Demonstrate the complete procedure with the same set of slide for both the medium speed condition and the fast speed condition.*

Do you have any questions?

Appendix C

INFORMED CONSENT

Visual Contrast Sensitivity

This study will determine the effects of several variables such as stimulus orientation, contrast, and movement on contrast sensitivity, which is a measure of visual acuity. You will receive one experimental credit each time you participate. Each experimental session will last from 40-50 minutes. You will be asked to participate in two experimental sessions.
You may terminate your participation at any time and you will receive experimental credit for your participation to that time.

There is no physical or psychological discomfort involved. We can not promise any benefits, but the tests can detect visual problems for which you should consult an optometrist or ophthalmologist. We will inform you about the purpose and results of this study when you have completed your participation. The information accumulated from this research might be presented at scientific meetings and/or published in professional journals and books, or used for any other purpose which the Department of Psychology at Virginia Tech considers proper in the interest of education, knowledge,
or research. Individual data will be coded to guarantee privacy and will
be seen only by the researchers and, if requested, the individual subject.

This project has been approved by the Virginia Tech Human Subjects Committee (HSC) and the Instructional Review Board (IRB). If you have any question about this research project, Please call:

Craig A. Croxton:	Primary researcher	951-3244
Dr. A. M. Prestrude:	Project sponsor	231-5673
Dr. R. J. Harvey:	Chair, HSC, Dept. of Psychology	231-7030
Dr. Ernest Stout:	Chair, IRB	231-5284

1. I acknowledge my voluntary participation in this study.

2. The study has been described to me and any questions I have about my participation have been answered.

3. I understand that information resulting from my participation may be used for scientific and educational purposes, but that I, and my data will not be identified by name.

4. I understand that this project has been approved by the Human Subjects Committee, and the Institutional Review Board.

5. I am participating freely and understand that I need not participate if I do not wish, and if I participated, that I may withdraw at any time without penalty.

Signature:________________________ SSN:_______________

Date:____________ Experimenter________________________

DATA COLLECTION SHEET

NAME:____________________ AGE:_______ SEX:_____ DATE: ______________ TRIAL # ____

Far Acuity: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Score:_________

Near Acuity: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Score:_________

CORRECTED:___________ ORIENTATION:___________ TESTER:___________

Vel	Order	Amp	LINE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	THLD	AVG
		250	1								UG				XXX				
											UG				XXX				
		125	2			UG									XXX				
						UG									XXX				
		85	3			UG									XXX				
						UG									XXX				
		50	5		UG									XXX					
					UG									XXX					
		37	7					UG									XXX		
								UG									XXX		
		25.5	10					UG							XXX				
								UG							XXX				
		17	15							UG							XXX		
										UG							XXX		
		12.8	20										UG			XXX			
													UG			XXX			

Vel	Order	Amp	LINE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	THLD	AVG
		250	1								UG				XXX				
											UG				XXX				
		125	2			UG									XXX				
						UG									XXX				
		85	3			UG									XXX				
						UG									XXX				
		50	5		UG									XXX					
					UG									XXX					
		37	7					UG									XXX		
								UG									XXX		
		25.5	10					UG							XXX				
								UG							XXX				
		17	15							UG							XXX		
										UG							XXX		
		12.8	20										UG			XXX			
													UG			XXX			

Vel	Order	Amp	LINE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	THLD	AVG
		250	1								UG				XXX				
											UG				XXX				
		125	2			UG									XXX				
						UG									XXX				
		85	3			UG									XXX				
						UG									XXX				
		50	5		UG									XXX					
					UG									XXX					
		37	7					UG									XXX		
								UG									XXX		
		25.5	10					UG							XXX				
								UG							XXX				
		17	15							UG							XXX		
										UG							XXX		
		12.8	20										UG			XXX			
													UG			XXX			

Vel	Order	Amp	LINE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	THLD	AVG
		250	1								UG				XXX				
											UG				XXX				
		125	2			UG									XXX				
						UG									XXX				
		85	3			UG									XXX				
						UG									XXX				
		50	5		UG									XXX					
					UG									XXX					
		37	7					UG									XXX		
								UG									XXX		
		25.5	10					UG							XXX				
								UG							XXX				
		17	15							UG							XXX		
										UG							XXX		
		12.8	20										UG			XXX			
													UG			XXX			

Table 1
Analysis of Variance Procedure

Dependent Variable: Contrast Sensitivity

Error Term: Subject x Orientation Ordering x Orientation

Source	DF	Mean Square	F-Value	Pr > F
Orientation Ordering	1	328.39	2.09	0.1588
Error	30	157.24		

Error Term: Subject x Orientation Ordering x Orientation

Source	DF	Mean Square	F-Value	Pr > F
Orientation	1	2844.05	18.09	0.0002
Error	30	157.24		

Error Term: Subject x Orientation x Velocity Ordering x Velocity

Source	DF	Mean Square	F-Value	Pr > F
Velocity Ordering	1	105.45	1.14	0.3326
Error	180	92.15		

Error Term: Subject x Orientation x Velocity Ordering x Velocity

Source	DF	Mean Square	F-Value	Pr > F
Velocity	3	14770.94	160.29	0.0001
Error	180	92.15		

(table continues)

Error Term: Subject x Orientation x Velocity Ordering x Velocity

Source	DF	Mean Square	F-Value	Pr > F
Orientation x Velocity	3	364.75	3.96	0.0092
Error	180	92.15		

Error Term: Subject x Orientation x Velocity Ordering x Velocity

Source	DF	Mean Square	F-Value	Pr > F
Orientation x Velocity Ordering	3	86.99	0.94	0.4206
Error	180	92.15		

Dependent Variable: Contrast Sensitivity

Source	DF	Mean Square	F-Value	Pr > F
Model	367	451.01	12.30	0.0001
Error	1680	36.66		

Source	DF	Mean Square	F-Value	Pr > F
Spatial Frequency Ordering	7	42.73	1.17	0.3194
Spatial Frequency	7	7191.84	196.18	0.0001
Orientation x Spatial Frequency	7	125.27	3.42	0.0012

(table continues)

Source	DF	Mean Square	F-Value	Pr > F
Velocity x Spatial Frequency	21	1075.80	29.35	0.0001
Orientation x Velocity x Spatial Frequency	21	27.38	0.75	0.7864
Orientation x Spatial Frequency Ordering	7	95.11	2.59	0.0116
Velocity x Spatial Frequency Ordering	21	18.37	0.50	0.9708
Orientation x Velocity x Spatial Frequency Ordering	21	22.289	0.61	0.9158

Table 2
Fisher's Least Significant Difference (LSD) for Velocity

T tests[a] (LSD) for variable: Contrast Sensitivity

Alpha = 0.05 DF = 180 MSE = 92.15393

Critical Value of T = 1.97

Least Significant Difference = 1.1839

T grouping[b]	Mean contrast sensitivity	N	Velocity
A	17.7592	512	STATIC
B	10.1856	512	SLOW
C	7.0836	512	MEDIUM
D	5.7621	512	FAST

[a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 3

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 1 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	47.53	1.78	0.1535
Error	124	1100.79		
Corrected Total	127	1148.32		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 8.8877344

Number of Means	2	3	4
Critical Range	1.480	1.556	1.605

Duncan grouping[b]		Mean contrast sensitivity	N	Velocity
A		6.1508	32	STATIC
A	B	5.3016	32	SLOW
A	B	5.1316	32	MEDIUM
	B	4.4392	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 4

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 2 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	1213.92	8.18	0.0001
Error	124	6132.96		
Corrected Total	127	7346.88		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 49.45938

Number of Means	2	3	4
Critical Range	3.493	3.673	3.789

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	16.225	32	STATIC
A	14.477	32	SLOW
B	9.623	32	FAST
B	9.075	32	MEDIUM

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 5

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 3 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	8979.95	32	0.0001
Error	124	11600.80		
Corrected Total	127	20580.75		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 93.5548

Number of Means	2	3	4
Critical Range	4.804	5.051	5.221

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	30.690	32	STATIC
B	18.701	32	SLOW
C	12.662	32	MEDIUM
C	8.452	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 6

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 5 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	16556.89	31.96	0.0001
Error	124	21414.94		
Corrected Total	127	37971.83		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 172.7011

Number of Means	2	3	4
Critical Range	6.527	6.863	7.080

Duncan grouping[b]		Mean contrast sensitivity	N	Velocity
A		38.152	32	STATIC
B		17.264	32	SLOW
B	C	10.950	32	MEDIUM
	C	9.900	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 7

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 7 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	8533.12	60.75	0.0001
Error	124	5806.08		
Corrected Total	127	14339.20		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 46.82326

Number of Means	2	3	4
Critical Range	3.398	3.574	3.686

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	28.641	32	STATIC
B	13.883	32	SLOW
C	9.897	32	MEDIUM
C	7.700	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 8

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 10 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	5421.82	19.20	0.0001
Error	124	11670.26		
Corrected Total	127	17092.08		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 94.115

Number of Means	2	3	4
Critical Range	4.818	5.066	5.226

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	23.419	32	STATIC
B	10.456	32	SLOW
B	8.331	32	MEDIUM
B	7.137	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 9

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 15 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	1404.06	25.96	0.0001
Error	124	2235.47		
Corrected Total	127	3639.53		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 18.02797

Number of Means	2	3	4
Critical Range	2.109	2.217	2.287

Duncan grouping[b]		Mean contrast sensitivity	N	Velocity
A		[illegible]38	32	STATIC
B		[illegible]8	32	SLOW
B	C	3.575	32	MEDIUM
	C	2.330	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 10

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Vertical Orientation @ 20 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	502.66	11.76	0.0001
Error	124	1766.56		
Corrected Total	127	2269.22		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 14.24643

Number of Means	2	3	4
Critical Range	1.875	1.971	2.033

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	7.3671	32	STATIC
B	2.9904	32	FAST
B	2.8309	32	SLOW
B	2.5867	32	MEDIUM

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 11

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 1 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	62.40	2.42	0.0689
Error	124	1064.04		
Corrected Total	127	1126.44		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 8.581

Number of Means	2	3	4
Critical Range	1.455	1.530	1.578

Duncan grouping[b]		Mean contrast sensitivity	N	Velocity
A		5.7837	32	SLOW
A	B	4.9473	32	STATIC
A	B	4.8395	32	MEDIUM
	B	3.8163	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 12

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 2 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	1147.56	6.40	0.0005
Error	124	7411.75		
Corrected Total	127	8559.31		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 59.77222

Number of Means	2	3	4
Critical Range	3.840	4.038	4.165

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	14.886	32	STATIC
A	13.184	32	SLOW
B	8.739	32	MEDIUM
B	7.693	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 13

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 3 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of Squares	F-Value	Pr > F
Model	3	5884.25	30.30	0.0001
Error	124	8026.27		
Corrected Total	127	13910.52		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 64.72797

Number of Means	2	3	4
Critical Range	3.996	4.202	4.334

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	23.919	32	STATIC
B	16.010	32	SLOW
C	8.646	32	MEDIUM
C	6.726	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 14

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 5 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	11054.40	28.48	0.0001
Error	124	16045.82		
Corrected Total	127	27100.22		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 129.4018

Number of Means	2	3	4
Critical Range	5.649	5.941	6.128

Duncan grouping[b]		Mean contrast sensitivity	N	Velocity
A		30.985	32	STATIC
B		13.394	32	SLOW
B	C	11.072	32	MEDIUM
	C	6.466	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 15

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 7 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	4801.88	36.90	0.0001
Error	124	5379.32		
Corrected Total	127	10181.20		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 43.38162

Number of Means	2	3	4
Critical Range	3.271	3.440	3.548

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	21.491	32	STATIC
B	11.264	32	SLOW
C	6.809	32	MEDIUM
C	6.191	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 16

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 10 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	2506.80	26.56	0.0001
Error	124	3901.55		
Corrected Total	127	6408.35		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 31.4641

Number of Means	2	3	4
Critical Range	2.786	2.929	3.022

Duncan grouping[b]	Mean contrast sensitivity	N	Velocity
A	15.719	32	STATIC
B	9.398	32	SLOW
C	5.788	32	MEDIUM
C	4.214	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 17

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 15 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	416.79	21.64	0.0001
Error	124	796.20		
Corrected Total	127	1212.99		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 6.420968

Number of Means	2	3	4
Critical Range	1.258	1.323	1.365

Duncan grouping		Mean contrast sensitivity	N	Velocity
A		6.1508	32	STATIC
B		5.3016	32	SLOW
B	C	5.1316	32	MEDIUM
	C	4.4392	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

Table 18

Analysis of Variance Procedure and Multiple Range Test of Contrast Sensitivity for Oblique Orientation @ 20 CPD

Dependent Variable: VELOCITY

Source	DF	Sum of squares	F-Value	Pr > F
Model	3	39.64	13.96	0.0001
Error	124	117.38		
Corrected Total	127	157.02		

Duncan's Multiple Range Test[a] for variable: Contrast Sensitivity

Alpha = 0.05 DF = 124 MSE = 0.946584

Number of Means	2	3	4
Critical Range	.4832	.5081	.5241

Duncan grouping	Mean contrast sensitivity	N	Velocity
A	3.6233	32	STATIC
B	2.4766	32	SLOW
B	2.3041	32	MEDIUM
B	2.2718	32	FAST

Note. CPD = cycles per degree. [a]This test controls the type I comparison wise error rate, not the experimentwise rate. [b]Means with the same letter are not significantly different.

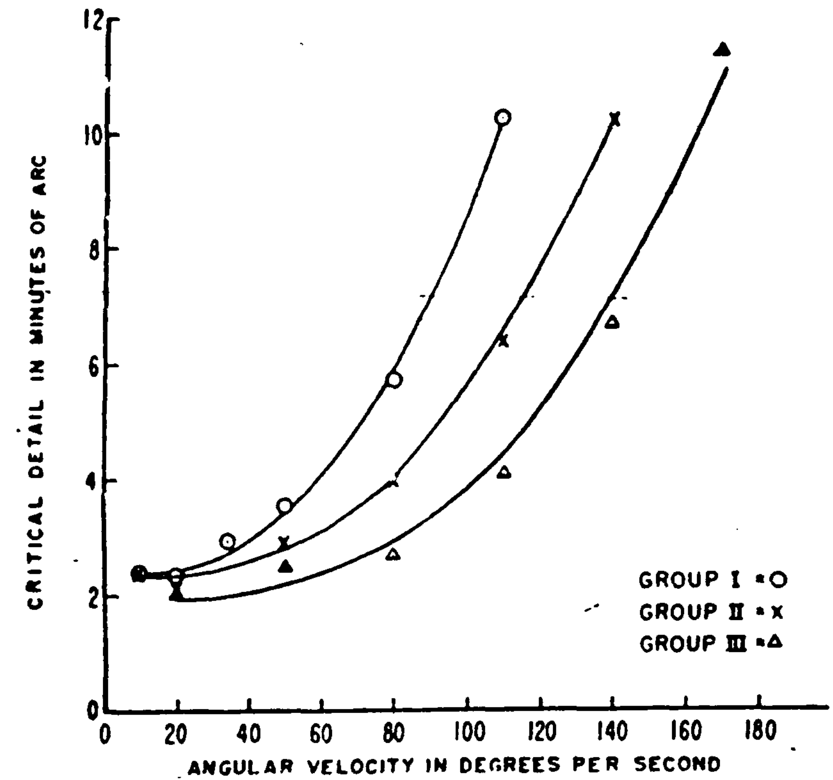

FIG. 2. Observed and computed threshold values of all subjects grouped according to performance level. The circles, crosses, and triangles are the observed values, the continuous lines are graphs of the equation $Y = a + bx^3$.

Figure 1. Ludvigh and Miller's Data Plots for the Relationship Between Visual Acuity and Angular Velocity. Note. From "Study of Visual Acuity druing the Ocular Pursuit of Moving Test Objects. I. Introduction" by F. Ludvigh and J. W. Miller, 1958, Journal of the Optical Society of America, 48, p. 800.

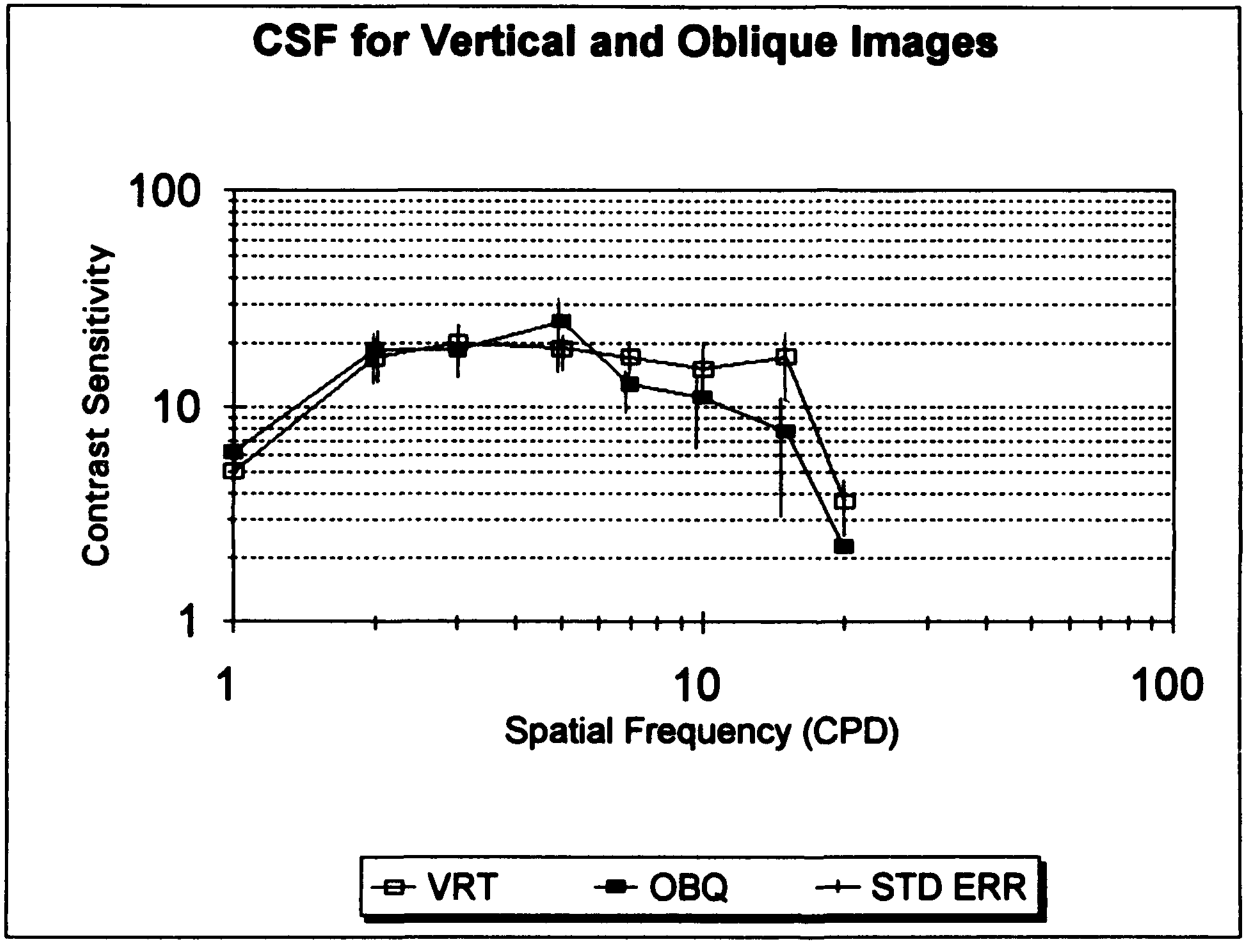

Figure 2. Pilot Study Contrast Sensitivity (Collapsed across Velocities) as a function of Spatial Frequency with Differing Orientations. CSF = Contrast sensitivity function. VRT = Vertical. OBQ = Oblique. STD ERR = Standard error.

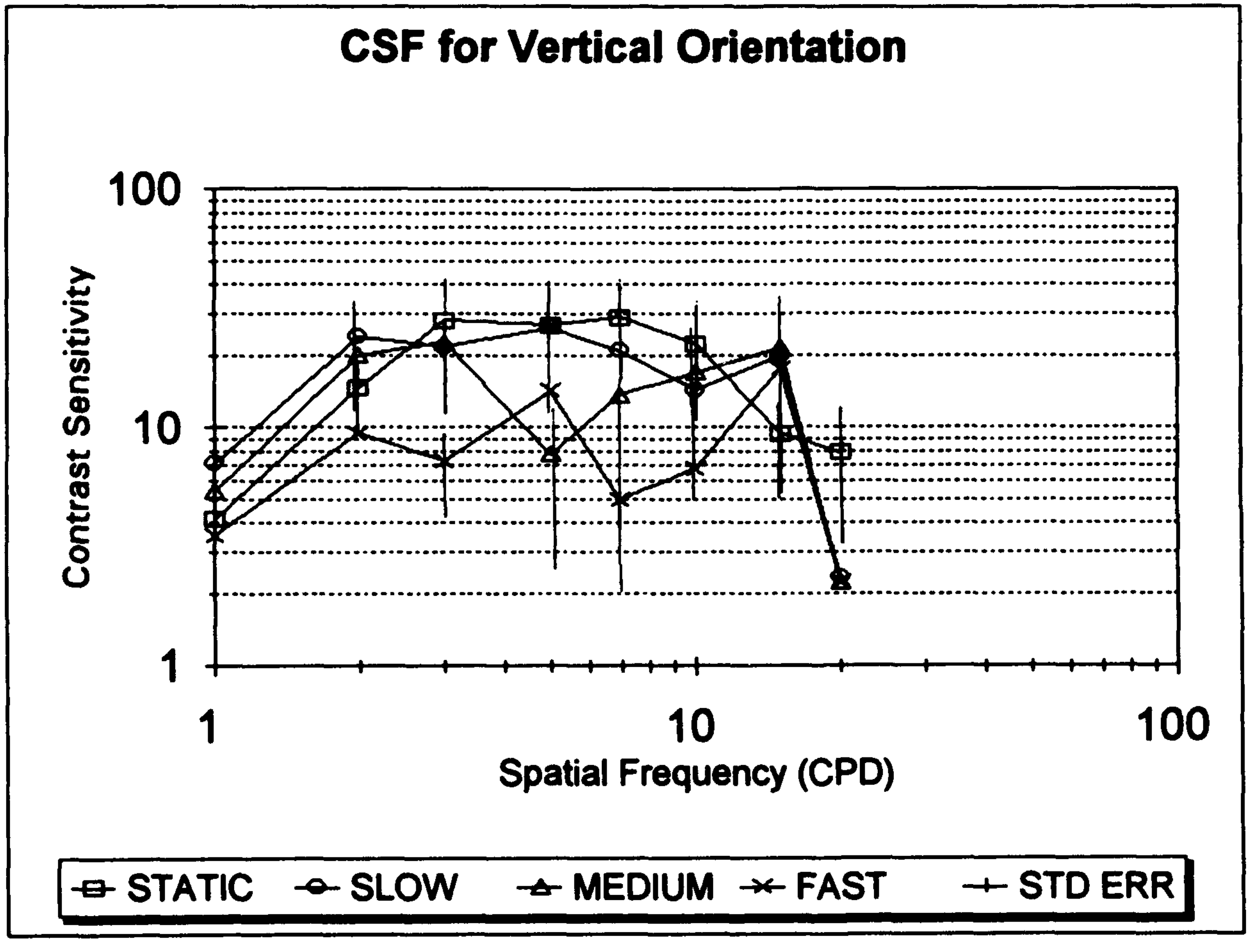

Figure 3. Pilot Study Contrast Sensitivity (Vertical Orientation) as a function of Spatial Frequency with differing Velocities. CSF = Contrast sensitivity function. STATIC = 0°/second. SLOW = 22°/second. MEDIUM = 30°/second. FAST = 39°/second. STD ERR = Standard error.

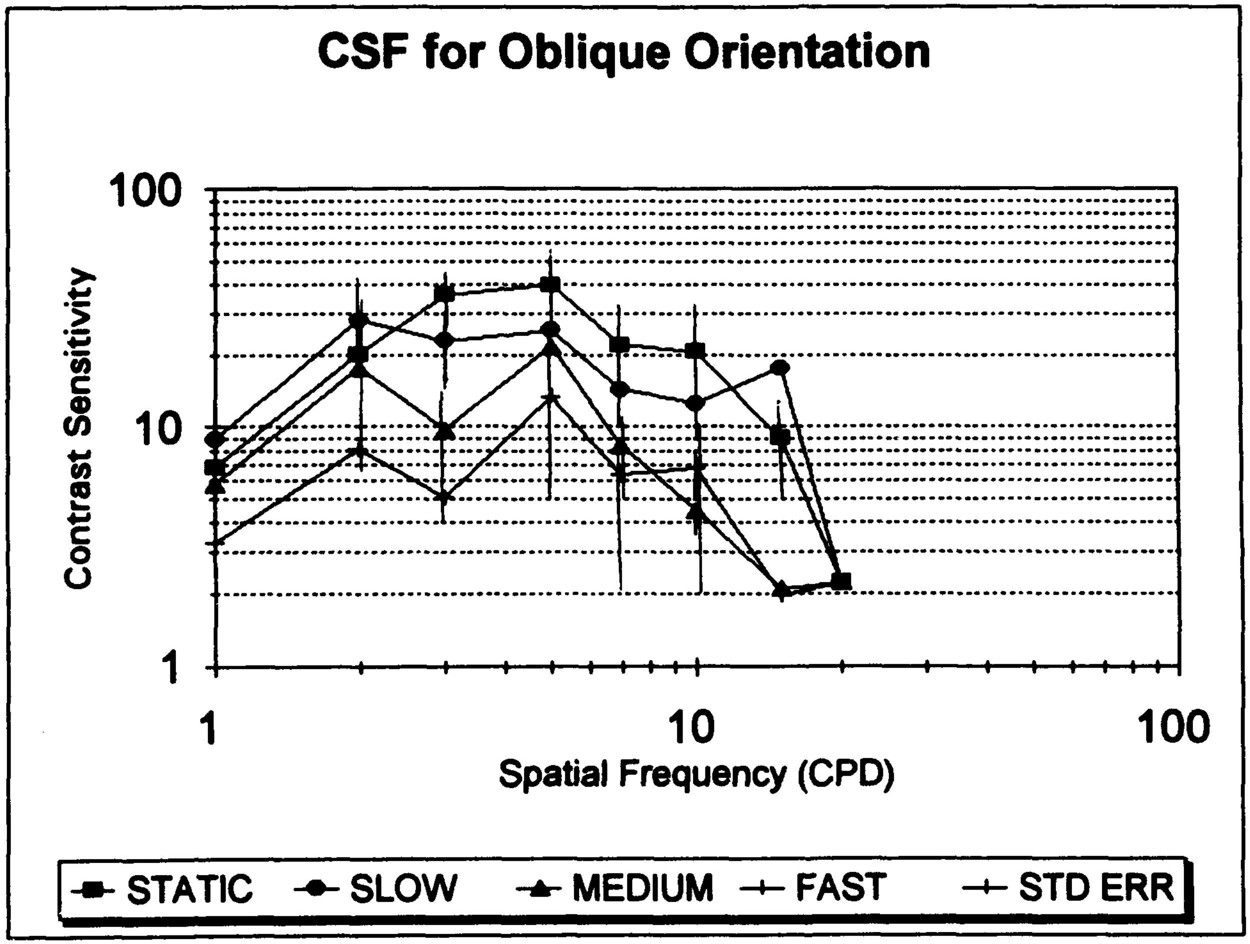

Figure 4. Pilot Study Contrast Sensitivity (Oblique Orientation) as a function of Spatial Frequency with differing Velocities. CSF = Contrast sensitivity function. STATIC = 0°/second. SLOW = 22°/second. MEDIUM = 30°/second. FAST = 39°/second. STD ERR = Standard error.

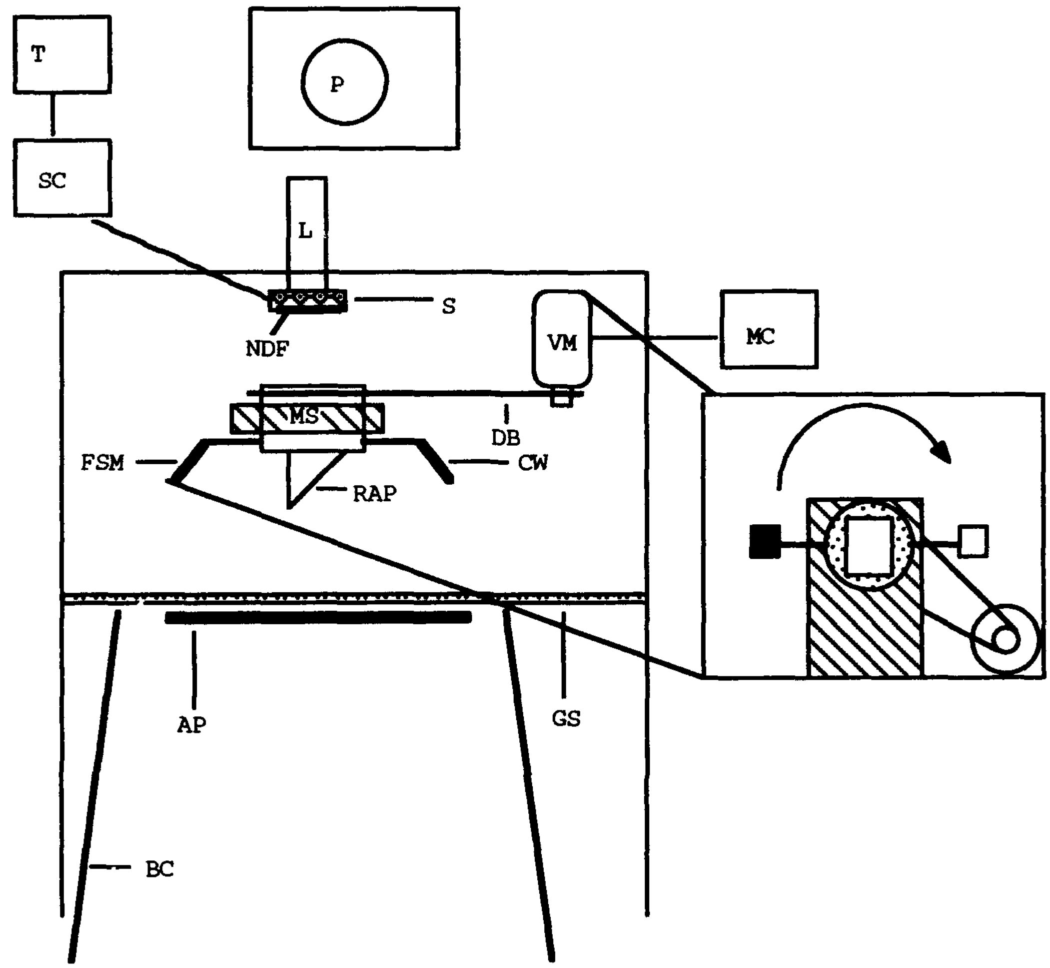

FIGURE 5. A schematic of the Portable Dynamic Contrast Sensitivity Device (PDCSD). T = timer; SC = shutter controler; P = projector; L = lens; S = shutter; NDF = neutral density filter; VM = variable speed motor; MC = motor controller; MS = mounting structure; DB = drive belt; FSM = front surface mirror; RAP = right angle prism; CW = counter weight; GS = ground glass screen; AP = adjustable aperture; BC = black cloth. The insert shows a front view of the rotating prism and mirror.

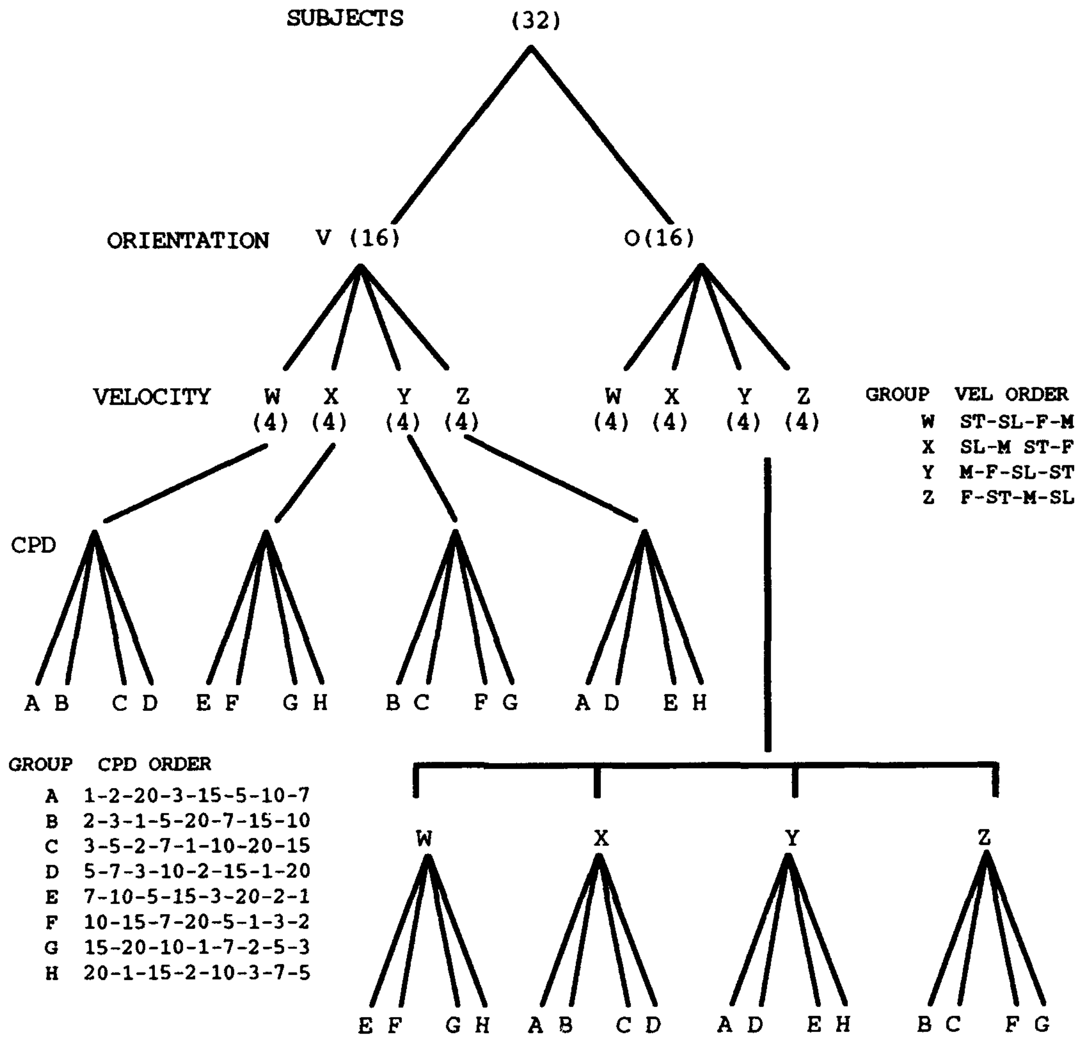

FIGURE 6. Row Latin Square design for the 32 subjects.
CPD = Cycles per degree.

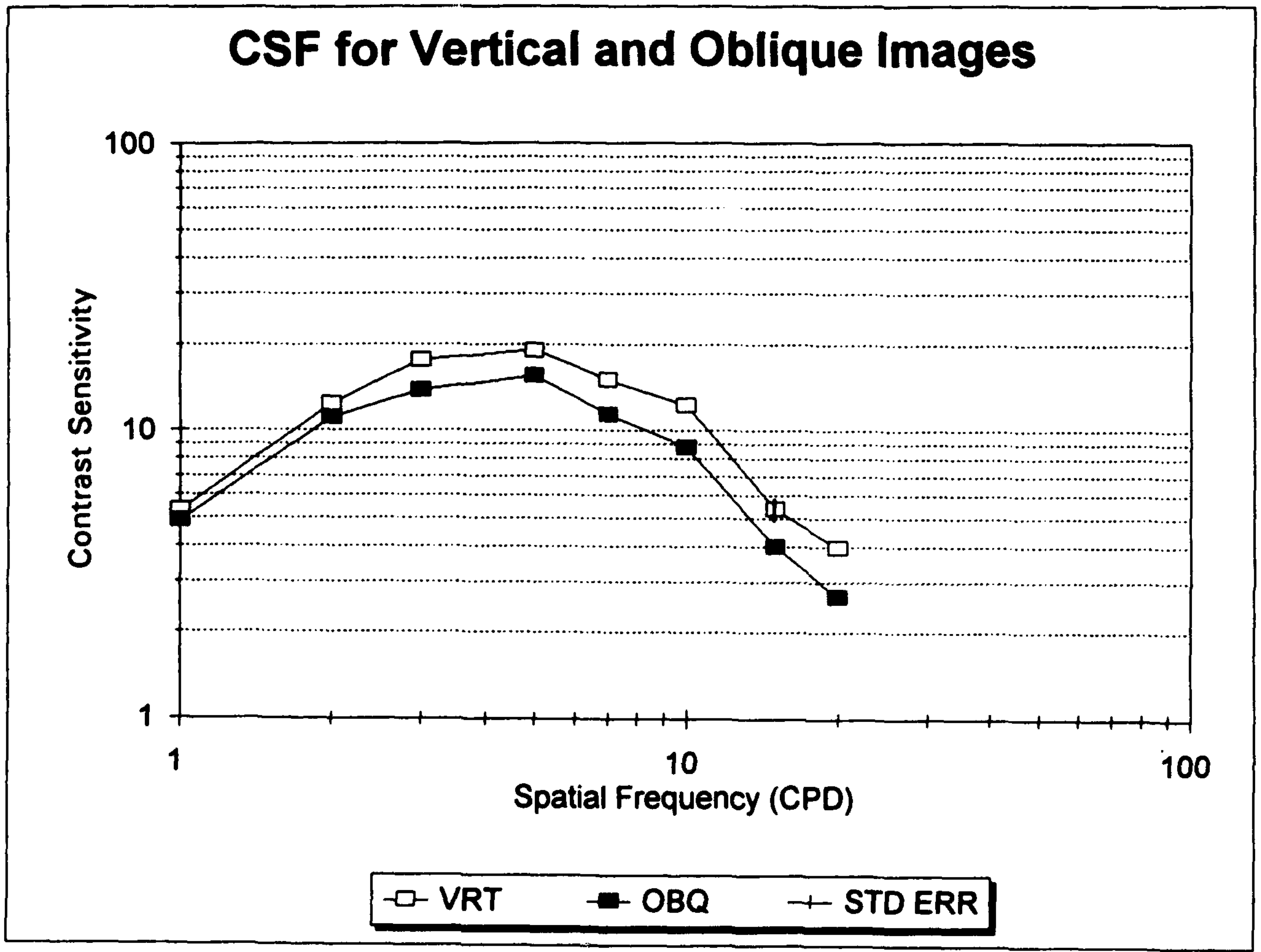

Figure 7. Contrast Sensitivity (Collapsed across Velocities) as a function of Spatial Frequency with Differing Orientations. CSF = Contrast sensitivity function. VRT = Vertical. OBQ = Oblique. STD ERR = Standard error.

Contrast Sensitivity Decrement from the Vertical to the Oblique Orientation as a Function of Spatial Frequceny

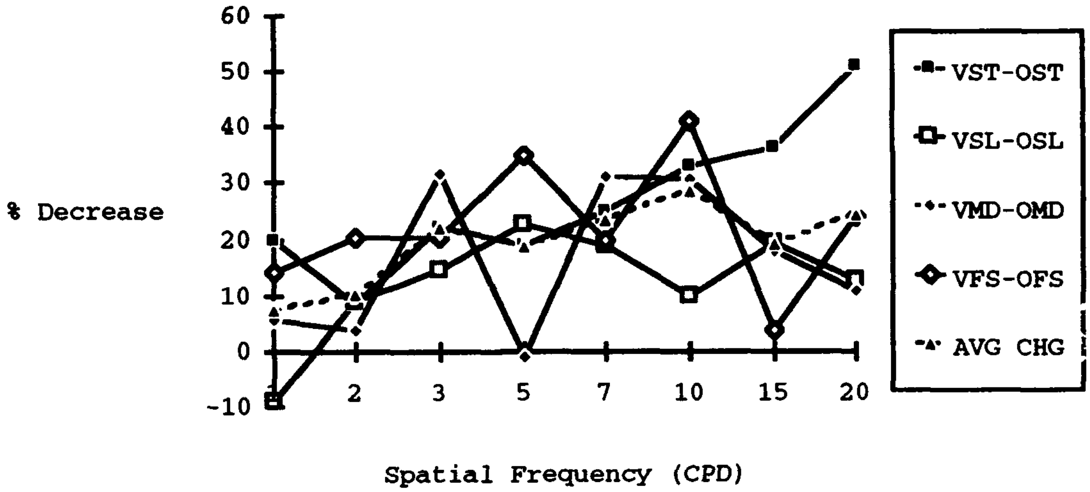

Figure 8. Contrast Sensitivity decrement from Vertical to Oblique Orientation as a function of Spatial Frequency. CPD = Cycles per degree. VST-OST = Vertical Static vs Oblique Static Velocity. VSL-OSL = Vertical Slow vs Oblique Slow Velocity. VMD-OMD = Vertical Medium vs Oblique Medium Velocity. VFS-OFS = Vertical Fast vs Oblique Fast Velocity. AVG CHG = Average % change between the Static, Slow, Medium, and Fast conditions.

Line of Best Fit for % Decrement from Vertical to Oblique Orientation

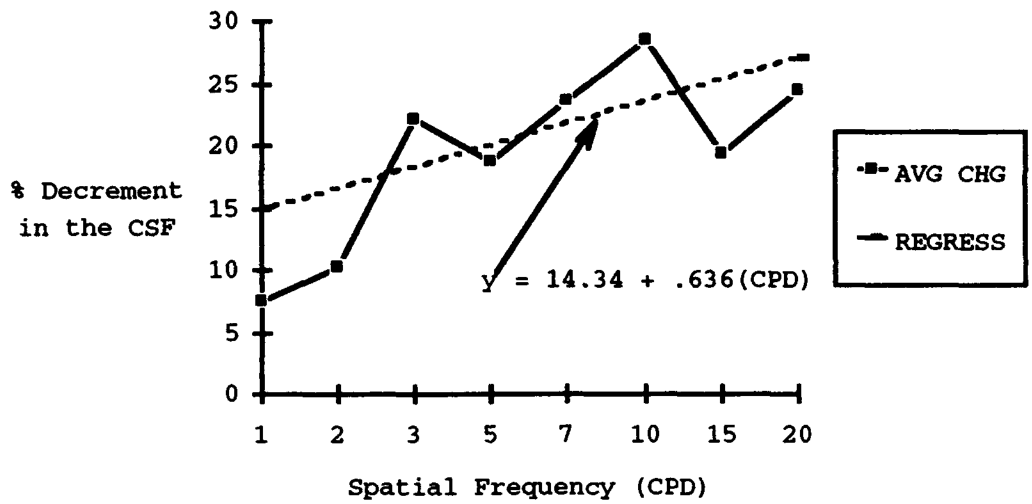

Figure 9. Line of Best Fit for the Decrement in Contrast Sensitivity from Vertical to Oblique Orientation as a Function of Spatial Frequency. CSF = Contrast sensitivity function. CPD = Cycles per degree. AVG CHG = Average % change in the CSF between Vertical and the Oblique orientation. REGRESS = Regression line.

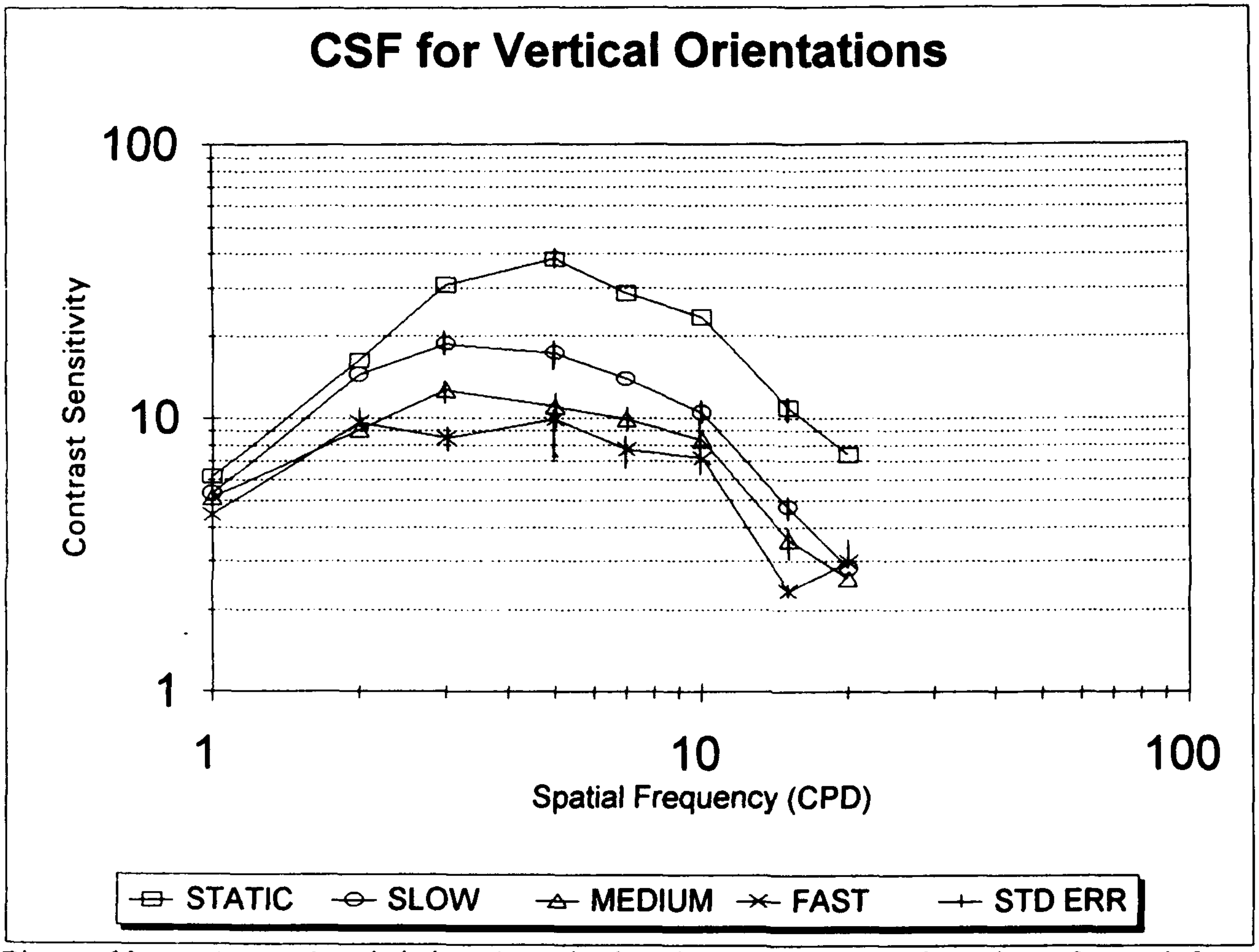

Figure 10. Contrast Sensitivity (Vertical Orientation) as a function of Spatial Frequency with differing Velocities. CSF = Contrast sensitivity function. STATIC = 0°/second. SLOW = 22°/second. MEDIUM = 30°/second. FAST = 39°/second. STD ERR = Standard error.

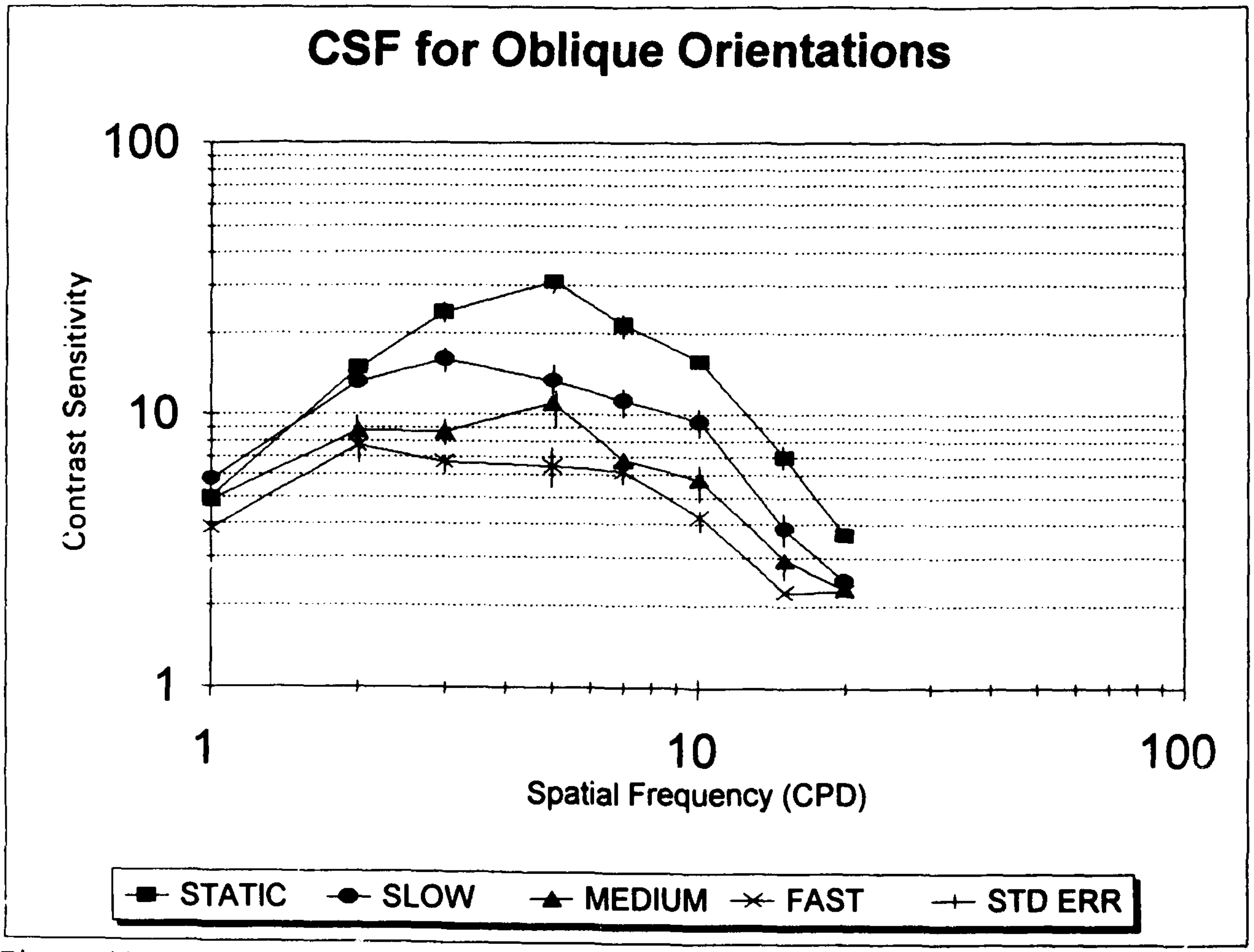

Figure 11. Contrast Sensitivity (Oblique Orientation) as a function of Spatial Frequency with differing Velocities. CSF = Contrast sensitivity function. STATIC = 0°/second. SLOW = 22°/second. MEDIUM = 30°/second. FAST = 39°/second. STD ERR = Standard error.

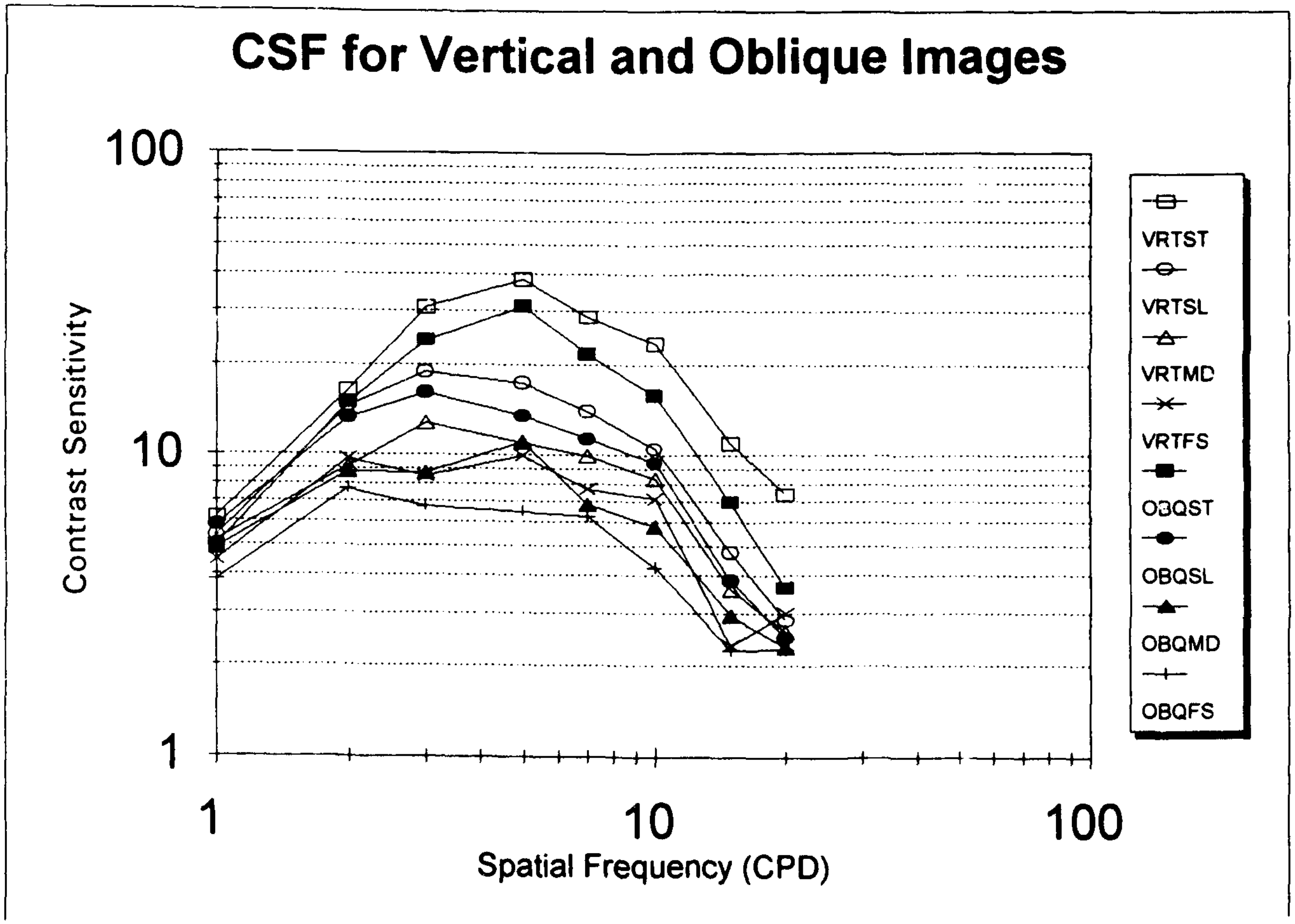

Figure 12. Contrast Sensitivity (Vertical and Oblique Orientations) as a function of Spatial Frequency with differing Velocities. CSF = Contrast sensitivity function. VRTST = Vertical @ 0^{o}/second. VRTSL = Vertical @ 22^{o}/second. VRTMD = Vertical @ 30^{o}/second. VRTFS = Vertical @ 39^{o}/second. OBQST = Oblique @ 0^{o}/second. OBQSL = Oblique @ 22^{o}/second. OBQMD = Oblique @ 30^{o}/second. OBQFS = Oblique @ 39^{o}/second.

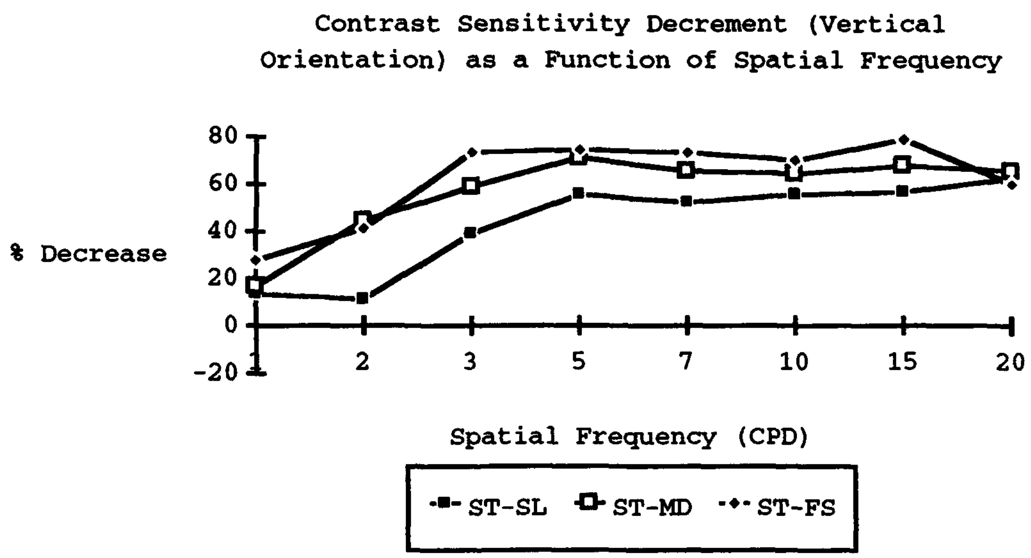

Figure 13. Percentage Decrease in the Contrast Sensitivity Function (Vertical Orientation) as a function of Spatial Frequency with changes in Velocities. ST-SL = Static vs Slow Velocity. ST-MD = Static vs Medium Velocity. ST-FS = Static vs Fast Velocity.

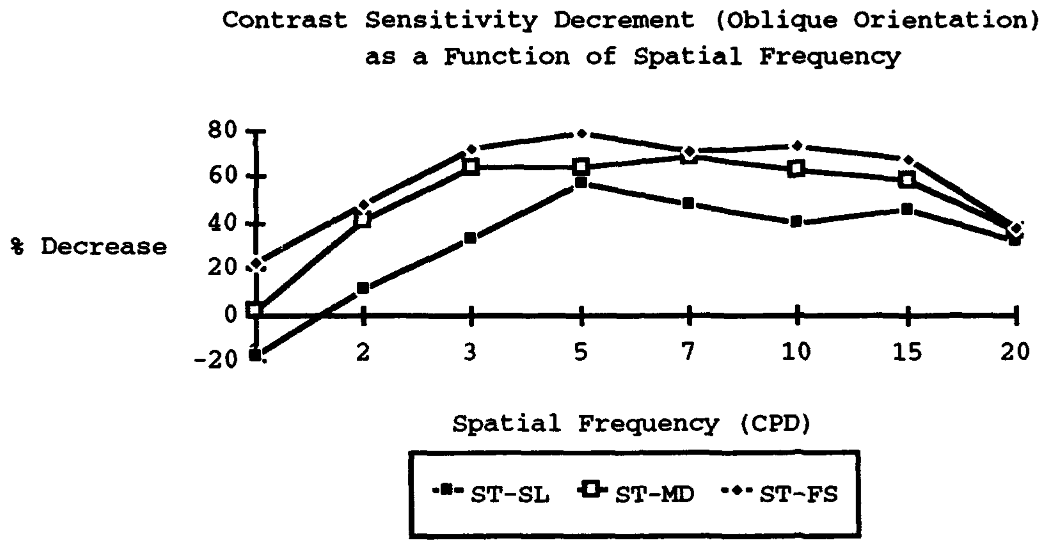

Figure 14. Percentage Decrease in the Contrast Sensitivity Function (Oblique Orientation) as a function of Spatial Frequency with changes in Velocities. ST-SL = Static vs Slow Velocity. ST-MD = Static vs Medium Velocity. ST-FS = Static vs Fast Velocity. Negative values represent increases in the CSF.

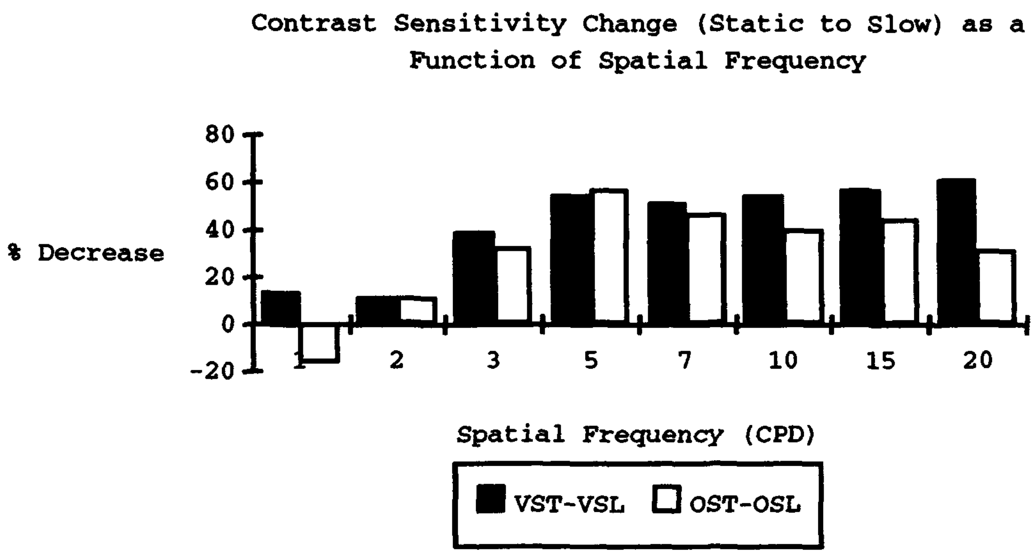

Figure 15. Change in Contrast Sensitivity (Static to Slow Conditions) as a Function of Spatial Frequency with differing Orientations. VST-VSL = Vertical Static to Vertical Slow condition. OST-OSL = Oblique Static to Oblique Slow condition. Negative values represent increases in the CSF.

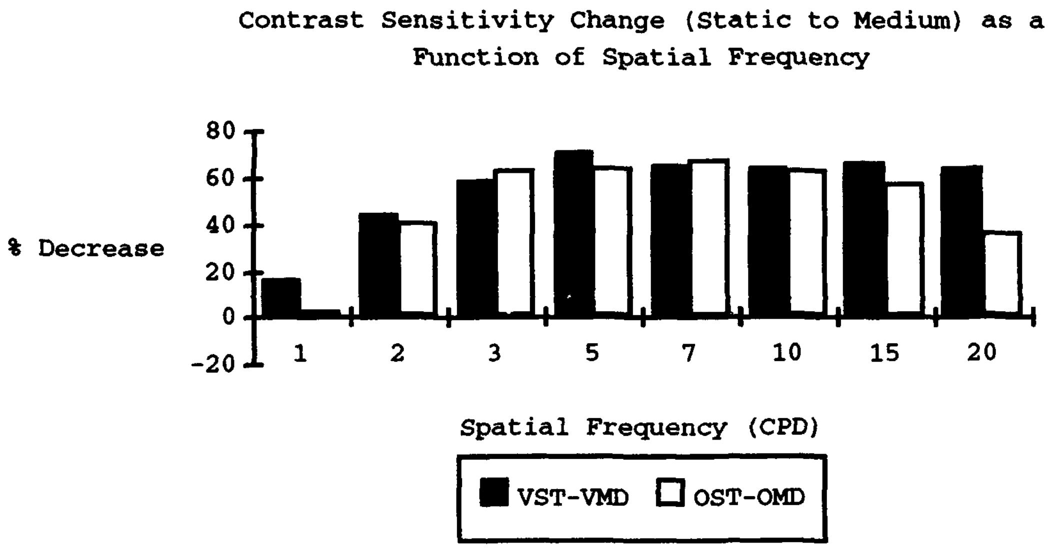

Figure 16. Change in Contrast Sensitivity (Static to Medium Conditions) as a Function of Spatial Frequency with differing Orientations. VST-VMD = Vertical Static to Vertical Medium condition. OST-OMD = Oblique Static to Oblique Medium condition.

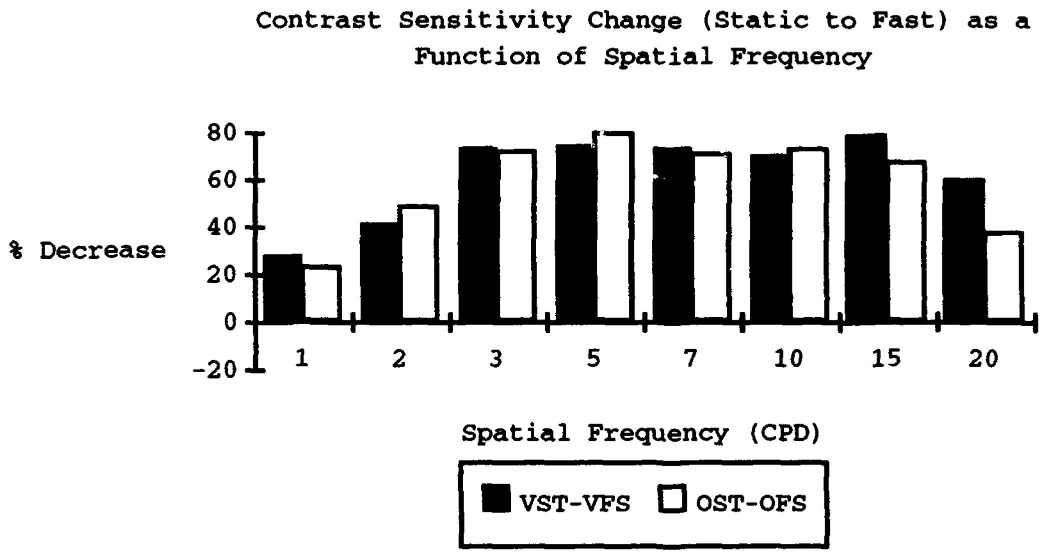

Figure 17. Change in Contrast Sensitivity (from Static to Fast Conditions) as a Function of Spatial Frequency with differing Orientations. VST-VFS = Vertical Static to Vertical Fast condition. OST-OFS = Oblique Static to Oblique Fast condition.

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THE EFFECTS OF TARGET ORIENTATION ON THE DYNAMIC CONTRAST SENSITIVITY FUNCTION

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Captain, United States Air Force

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Chairman: Albert M. Prestrude, Department of Psychology

(ABSTRACT)

Much research has been accomplished on the effects of target motion on visual acuity. Research has also been accomplished on the effects of target orientation on visual acuity. The contrast sensitivity function (CSF) also has been studied as a predictor of visual performance under dynamic conditions. However, no previous studies have combined these areas of research and examined the effect of target orientation on the Dynamic Contrast Sensitivity Function (DCSF).

This study examined the effects of target orientation on the DCSF and found that diagonal lines (relative to vertical lines) decreased the DCSF, on average over 19%. Previous research indicated that target motion reduces contrast sensitivity, and at the same time shifts the peak of the CSF toward lower spatial frequencies. This study rotated the target in a circular path (velocities of 22°, 30°, and 39°/second) and found a similar decrement and shift in the CSF.

The main effects for Target Orientation, Velocity, and Spatial Frequency and their two-way interactions were all

statistically significant ($p \leq .05$). Additionally, all velocity conditions were found to be statistically different from each other. These results advance the validity of our measurement device and procedures.

The effect of target orientation presumably is a function of the magnocellular and parvocellular visual pathway systems and their roles in the detection of form and motion. While the magnocellular system is primarily responsible for detection of motion and large objects, the parvocellular system is responsible for the detection of color and fine detail.

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